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EXTENSION OF SASKATCHEWAN ORGANIC ON-FARM RESEARCH: PART II: SOIL FERTILITY AND WEED MANAGEMENT

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Saskatchewan Organic On-Farm Research: Part II: Soil Fertility and Weed Management

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1) Abstract

This studies objective was to evaluate agronomic practices on organic farms. Rock phosphate increased yield slightly in yield in the year of application. *Penicillium bilaae* increased yield slightly however when applied in combination with rock P was no more effective than *P. bilaiae* applied alone. Composted manure was effective in increasing plant P uptake, total biomass production and yield at most sites. Of the annual green manures tested Indianhead lentil increased N and P uptake in the subsequent crop. Chickling vetch, buckwheat, fenugreek and annual alfalfa were poor at establishing under organic conditions. Modern barley and oat varieties yielded more than heritage varieties. In contrast the heritage wheat variety Red Fife often had the highest yield. The optimum plant densities for annual green manures are from 223 to 300 plants m^{-2} for lentil, 49 to 78 plants m^{-2} for field pea, and 24 plants m^{-2} for chickling vetch.

2) Executive Summary

The overall objective of this study was to evaluate specific organic soil amendments, crop rotations, and crop varieties for their affect on soil fertility, weed densities, and crop productivity in organic cropping systems. Despite difficulties due to drought and grasshopper damage we have found several significant results. We observed a small but significant overall increase in yield due to the application of rock phosphate in the year of application. It is unlikely that the addition of rock P will produce an economic return for organic producers. Overall applications of *P. bilaiae* increased yield slightly in the treatment crops. *Penicillium bilaiae* applied in combination with rock P was no more effective than *P. bilaiae* applied alone, indicating that it is not preferentially solubilizing P from rock P over soil P. The application of composted manure was effective in increasing plant P uptake and tissue concentrations, as well as total biomass production and yield at all of the sites except the adequately fertile Kernen site. In general, annual applications were more effective than single applications, although there was carry-over of the single applications into subsequent years. Of all the annual green manure crops examined, Indianhead lentil proved to be the most promising. Oilseed radish did well in cool, wet years. Chickling vetch, buckwheat, fenugreek and annual alfalfa are not recommended as green manures crop in organic production because of poor establishment and growth. Regardless of the green manure crop early incorporation is recommended to conserve soil water resources. Generally speaking sweetclover was the best green manure for supplying N and P although it reduced the yield of the subsequent crop because of excess use of water. Of the annual green manures tested Indianhead lentil performed fairly well in terms of its N and P contribution to the subsequent crop. Oilseed radish and fall rye also performed well for supplying nutrients as well as controlling weeds, but because they are non-leguminous they not add N to the system. It appears to be unnecessary to grow non-leguminous crops such buckwheat specifically for P solubilization, as the legumes are able to perform this function. Modern barley and oat varieties perform better than heritage varieties under organic conditions. In contrast the heritage wheat variety Red Fife consistently had amongst the highest yields on low nutrient organic farms. No significant differences in yield between the durum varieties were observed. The oat and barley genotypes that plant breeders had selected based on their potential in low input cropping systems performed quite well under on organic farms. This indicates that there is potential for selecting crop varieties specifically for organic crop production. The optimum plant densities for annual green manures under organic production are from 223 to 300 plants m^{-2} for lentil, 49 to 78 plants m^{-2} for field pea, and 0 to 24 plants m^{-2} for chickling vetch. Both lentil and field pea make

good annual green manure crops but the seeding rate of lentil needs to be increased (approx. double the current recommendation). In addition lentil must be terminated early to prevent the weeds from overwhelming the stand. Chickling vetch was the least economically feasible crop of the three species, due to a limited nitrogen contribution, a very large seed size, and high seed cost. Because of this it is not recommended as a green manure crop under organic conditions unless producers can produce their own seed for low cost. Overall this research has succeeded in evaluating and optimizing several crop management practices in organic crop production.

3) Technical Report

Background

Society has increased concerns regarding health and the environmental impacts of high input farming. A heightened awareness of sustainability in agriculture systems, coupled with the attraction of lowered input costs and premium prices for organic commodities, makes organic farm management a viable and responsible solution. This attitude is reflected in the rapid growth of the organic agriculture sector in recent years. Macey (2001) reports an almost 500% increase in organic land acreage in Saskatchewan in 1999 alone. Presently, more than one third of Canadian organic farmers reside in Saskatchewan (Canadian Organic Grower, Winter 2006). Despite the rapid expansion in this sector, however, little emphasis has been placed on organic agriculture from a research perspective. Until recently, most experimentation and advancement in the industry had been the responsibility of growers. Farmers have been innovative and have adapted to local circumstances and situations through self directed, trial-and-error research. This research has been, and continues to be, an integral part of organic agriculture in Saskatchewan. It is also imperative to continue to study cropping systems, weed management, and soil fertility in relation to organic systems in controlled experiments throughout the province, in order to provide growers with more information and resources.

3.0 Experiments

3.1 Experiment 1. The Evaluation of Rock Phosphorous and *Penicillium bilaiae* for Increasing Phosphorous Availability in Organic Crop Production.

Objective

The objective of this experiment was to determine the effect of varying rates of annual and one-time applications of rock phosphorous and *Penicillium bilaiae* on phosphorous availability and grain yield in organic crop production.

Materials and Methods

Field trials were conducted at Vonda, Elbow, Scott and Kernen, in the black, brown, and dark brown soil zones, respectively for 4 consecutive years. The Kernen and Vonda2 sites were added in 2004 because the Elbow site had experienced two crop failures due to drought and grasshoppers. The Scott site was managed by AAFC staff. The experimental design was an RCBD with four replicates. Soil tests were taken prior to seeding in the initial year to determine existing fertility levels (Table 1). At the Vonda and Elbow locations, AC Elsa wheat was seeded in 8 inch rows with a target density of 250 plants m^{-2} in 2002 and 2003. Due to drought conditions and grasshopper infestation, the trials in 2002 were terminated. In 2004 the experiments were recropped to CDC Mozart peas at a density of 100 plants m^{-2}. In 2005, these experiments were sown to AC Elsa wheat (250 plant m^{-2}). The Scott location was sown to AC Elsa wheat in 2002 and was recropped with Espace peas in 2003. Ten inch row spacing was used for both crops. In 2004, the trials were seeded to barley (250 plant m^{-2}). The Kernen

location was established in 2004, where plots were seeded to AC Elsa wheat in 8 inch rows with a target density of 250 plants m^{-2}. In 2005, this location was seeded with Delta peas in 8 inch row with a density of 100 plants $^{-2}$. Granular Blackgold® rock phosphorous was side banded at a 1 inch offset during seeding (see Table 2, Appendix 1 for chemical composition). Rock phosphorous was applied at rates of 0, 20, 40, 50, and 100 kg ha^{-1}, as annual and single (one-time) application treatments at all locations in the initial year of the study. All annual application treatments received a rock phosphorous application in the second and third years of the study. Rock phosphorous was not applied to the single application treatments in the second and third years of the study, as those treatments were a one time application only. *Penicillium bilaiae* (JumpStart®) was applied at recommended label rates as a seed treatment prior to seeding. All *P. bilaiae* treatments were inoculated with the fungi each experimental year, with the exception of the treatment with no rock phosphate and a single application of *P. bilaiae*. This treatment was only inoculated in the first year of the study and did not receive any repeat applications in the remaining years of the study. At all locations, trials were initiated on cereal stubble. All sites were tilled prior to seeding, with the exception of Vonda in 2002. Tillage was not implemented in order to conserve moisture, since severe drought conditions were present at this location. Post emergent harrowing with a flex-tine harrow was used to control early flushes of weeds at the Elbow, Vonda, and Kernen locations for all site years. Plant density, biomass dry weight, plant tissue N and P levels, and grain yield data were collected. Plant density counts were recorded approximately one month after seeding, using $1/4m^2$ quadrants (50cm x 50cm) at the front and back of each plot. Biomass samples were collected at 6 (early) and 12 (late) weeks, using $1/4m^2$ quadrants at the front and back of each plot. Samples were dried in a drying oven at 70 °C for a 48 hour period. All samples were averaged to provide values for each plot.

TABLE 1. Pre-seeding Soil Analysis for Rock Phosphorous Amendment Trial

	Location						
Soil Property	**Vonda**	**Scott**	**Elbow**	**Vonda**	**Elbow**	**Kernen**	**Vonda2**
	2002	2002	2002	2003	2003	2004	2004
Nitrogen (NO_3-N)	40.5	35.9	24.5	22	15	107	17
Phosphorus (P_2O_5-P)	6.1	12	5.6	14	14	65	14
Potassium (K)	537.9	419.8	128.9	779	690	1200	666
Sulfur (SO_4-S)	1.8	7	37.1	29	28	41	96
pH levels	7.1	5.5	7.3	7.7	7.6	7.9	7.9

Nutrients are reported in lb/acre

Results and Discussion

Averaged over sites and years, rock phosphorous and *P. bilaiae* applications increased yield in the treatment year compared to untreated controls (Table 2). However, increasing the rate of application of rock P did not result in a relative increase in yield. Inoculation of seed with *P. bilaiae* resulted in an overall yield increase (Table 2) in crops in the treatment application year.

TABLE 2. Overall Yield Production of Rock Phosphorous and *P. bilaiae* Treatments

Treatment	Yield	
Rock P (kg ha^{-1})	*kg ha^{-1}*	
0	883.35	b
20	933.14	a
40	919.74	ab
50	905.03	ab
100	900.3	ab
P. bilaiae		
treated	944.48	a
untreated	872.14	b

Contrasts	Estimate	SE	t statistic	P > [t]
Rock P vs. no Rock P	31.21	14.96	2.09	0.0381
P. bilaiae vs. no *P. bilaiae*	72.34	17.74	-4.08	0.0088

Values within a column followed by the same letter are not significantly different according to lsd (0.05).
Single degree of freedom contrasts were performed to determine the difference between groups of treatments. The estimate is the difference between the means of these treatments. The difference is considered significant if P< 0.05.

Within site years, *P. bilaiae* treatments had an effect on trial parameters at Elbow (Table 3). Yield, emergence and total biomass production was higher in the *P.bilaiae* treated plots than the non-treated controls at this site.

TABLE 3. Effect of *P. bilaiae* on Yield, Emergence, and Biomass at Elbow in 2002 & 2003

	Yield	Emergence		Biomass
	kg ha^{-1}	*pl m^{-2}*		*kg ha^{-1}*
Treatment	Elbow 02	Elbow 02	Elbow 03	Elbow 03
P. bilaiae	191.73a	128.75a	156.41a	856.71a
no *P. bilaiae*	80.18b	80.2b	121.5b	709.63b
LSD (P=.05)	35.00	12.59	13.34	111.82
CV	40.31	19.18	15.42	23.01

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Although there was no measurable response in yield, emergence and biomass at the other sites, plants at the Vonda (and Elbow) sites did produce more biomass and exhibited more P-uptake (P<0.10) at the 6 week sampling. Plants often exhibit an early response to added P-fertilizer. Early P-responses are particularly evident in cool, wet spring conditions. Although the early P-response does not always translate into higher yields at maturity (as we saw here) they do indicate a healthier plant that is more able to tolerate adverse conditions.

There were no significant overall affect of any of the treatments in the years of recropping for this trial when the data for all years and locations was analyzed together. This indicated that yearly reapplication of the *P. bilaiae* inoculant would be valuable. When the sites and years were analyzed separately, of all of the sites, the Elbow site had the lowest fertility level in our trials (Table 1). Both soil N and P were extremely low at this site and probably account for why this site was more responsive than the others. The Kernen site, set up on the University of Saskatchewan experimental farm, was considerably more fertile than the other sites, and represented an adequate fertility site. The Vonda and Scott sites had similar values of N and P, but very different soil pH levels. Bench top studies performed in conjunction with these field trials indicate that the *P. bilaiae* organism performs better in well buffered higher pH soils, such

as those at Elbow and Vonda, than acidic soils, such as those at Scott (Takeda, 2004). This is probably why we observed early P responses at the Vonda site, but no response at the Scott site. One inherent difficulty with performing these types of experiments on certified organic land is that we are unable to include positive P controls in the experimental treatments, because we cannot apply inorganic fertilizer P to the soil. It is difficult to definitively determine an optimal P response.

In summary, we observed a small but significant overall increase in yield due to the application of rock phosphate in the year of application. It is unlikely that the addition of rock P will produce an economic return for organic producers, but it may provide a long-term measure for returning P to the soils. In the short-term, soils contain sufficient stores of P. But with continued harvest and export of P from the land, without returning it, soils will become more and more inherently deficient. Overall applications of *P. bilaiae* increased yield in the treatment crops. *Penicillium bilaiae* applied in combination with rock P was no more effective than *P. bilaiae* applied alone, indicating that it is not preferentially solubilizing P from rock P over soil P. While short-term plant available P supplies are increasing yields, eventually without the addition of some form of P the soils will become increasingly unable to meet the supply.

3.2 Experiment 2. Evaluation of Organic Compost Amendments for Increasing Phosphorous Availability.

Objective

The objective of this experiment was to evaluate the effect of composted manure on phosphorous availability in organic crop rotations. This experiment examined the effects of varying application rates in one-time and subsequent yearly applications of composted manure.

Materials and Methods

Trials were conducted at Vonda, Elbow, Scott and Kernen in the black, brown, and dark brown soil zones, respectively from 2002 to 2005. The experimental design was an RCBD with four replicates. Soil tests were taken prior to seeding each year to determine existing fertility levels (Table 4.). The experiment was initiated on wheat stubble at all locations. AC Elsa wheat was seeded in 8 inch rows with a target density of 250 plants m^{-2} at the Elbow and Vonda locations in 2002 and 2003. Due to severe drought conditions, the trials in 2002 were terminated. These experiments were recropped to CDC Mozart peas (density 100 pl m^{-2}) in 2004, and to AC Elsa wheat (250 pl m^{-2}) in 2005. The Scott location was sown to AC Elsa (250pl m^{-2}) in 2002 and Espace peas in 2003. Ten inch row spacing was used at this location. In 2004 the Scott location was recropped to barley (250 pl m^{-2}). The Kernen location was initiated in 2004, where plots were sown to AC Elsa (250pl m^{-2}). In 2005, this location was recropped to Delta pea (250 pl m^{-2}). Composted cattle manure was manually spread at rates of 0, 5, 10, and 20 tonnes ha^{-1}, depending on annual or single application; these rates correspond to additions of 20, 40, 80 kg P ha^{-1}. Compost was incorporated with a cultivator immediately prior to seeding at all sites. Post emergent harrowing with a flex-tine harrow was used to control early flushes of weeds at the Elbow, Vonda, and Kernen locations. Plant density, biomass dry weight, plant tissue N and P levels, and grain yield data were collected throughout the growing seasons. Plant density counts were recorded approximately one month after seeding, using 1/4m^2 quadrants (50cm x 50cm) at the front and back of each plot. Biomass samples were collected at 6 (early) and 12 (late) weeks, using 1/4m^2 quadrants at the front and back of each plot. Samples were

dried in a drying oven at 70 ºC for a 48 hour period. All samples were averaged to provide values for each plot.

TABLE 4. Pre-seeding Soil Analysis for Compost Amendment Trial

	Location						
Soil Property	**Vonda**	**Scott**	**Elbow**	**Vonda**	**Elbow**	**Kernen**	**Vonda2**
	2002	2002	2002	2003	2003	2004	2004
Nitrogen (NO_3-N)	40.5	35.9	24.5	22	15	118	17
Phosphorus (P_2O_5-P)	6.1	12.0	5.6	14	14	73	14
Potassium (K)	537.9	419.8	128.9	799	690	1080	666
Sulfur (SO_4-S)	1.8	7.0	37.1	29	28	44	96
pH levels	7.1	5.5	7.3	7.7	7.6	7.1	7.9

Nutrients are reported in lb/acre

Results and Discussion

Year 1:

There were no overall effects from the manure application year of this trial when the sites and years were analyzed together. There were differences when the sites were analyzed separately. At Elbow, manure application had an effect on 1000 seed weight (Table 5) and P content in the seed (Table 6). At this site compost applications of 10 t ha^{-1} or higher resulted in plants with larger seeds with higher P concentrations in the seed. Seed P is the only source of P available to germinating and emerging seedlings, so higher levels of seed P can confer an advantage in early establishment of a crop (Yan et al., 1995).

TABLE 5. Effect of Compost Application on Seed Weight in Year 1 at Elbow

Compost Treatment	**Seed Weight**	
t ha^{-1}	*g*	
0 (a)	19.52	c
5 (a)	19.85	bc
10 (a)	20.66	ab
10 (s)	20.79	ab
20 (s)	20.57	ab

Contrasts	Estimate	SE	t statistic	P > [t]
Elbow				
manure vs. no manure	0.9	0.297	3.18	0.0079
annual vs. no manure	0.73	0.325	2.24	0.0445
Single year vs. no manure	1.16	0.325	3.57	0.0039
Vonda 2				
Single year vs. no manure	0.9	0.407	2.21	0.0472

*based on 1000 seed weights

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

TABLE 6. Effect of Compost Application on Seed P Concentration in Year 1 at Elbow

Compost Treatment *t ha^{-1}*	**Seed P Concentration** *mg g^{-1}*	
0 (a)	3.24	c
5 (a)	3.32	bc
10 (a)	3.37	abc
10 (s)	3.54	ab
20 (s)	3.57	a

Contrasts	Estimate	SE	t statistic	P > [t]
manure vs. no manure	0.2	0.08	2.65	0.0212
single year vs. no manure	0.31	0.09	3.61	0.0036
annual vs. single	-0.2	0.07	-2.92	0.0128

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Similar to the previous experiments (rock P and *P.bilaiae* applications) the Elbow site overall was more responsive to the composted manure applications than the other sites, exhibiting increases in biomass, plant nutrient uptake and seed nutrient concentrations (Table 7). Plants at the Vonda site did not produce more biomass in the manured treatment, but did have higher plant P concentrations compared to no manure controls (Table 7). The Scott site actually had lower biomass biomass production when manure was added, but not differences in nutrient contents.

TABLE 8. Result of Contrast Analysis of Biomass, Plant and Seed Nutrients in Year 1 at Elbow, Vonda, and Scott.

BIOMASS

Location	Year	Contrasts	Estimate	SE	t statistic	P > [t]
Elbow	2003	manure vs. no manure	335.78	128.08	2.62	0.0223
		single year vs. no manure	412	140.3	2.94	0.0125
Vonda	2003	annual vs. no manure	-822	364.7	-2.25	0.0437
Scott	2002	manure vs. no manure	-52	17.95	-2.9	0.0134
		annual vs. no manure	-52.1	19.67	-2.65	0.0212
		single year vs. no manure	-51.8	19.67	-2.64	0.0217

PLANT UPTAKE & CONCENTRATION

Location	Nutrient	Contrasts	Estimate	SE	t statistic	P > [t]
Elbow	N Uptake	manure vs. no manure	3.67	1.67	2.2	0.0484
		single year vs. no manure	4.71	1.83	2.58	0.0243
	P Uptake	manure vs. no manure	0.35	0.14	2.47	0.0296
		single year vs. no manure	0.42	0.16	2.69	0.0196
Vonda	P Conc	annual vs. no manure	0.27	0.12	2.2	0.0482
		annual vs. single	0.23	0.1	2.32	0.0384

SEED UPTAKE

Location	Nutrient	Contrasts	Estimate	SE	t statistic	P > [t]
Elbow	P	single year vs. no manure	0.47	0.17	2.76	0.0194

Year 2 :

In year two of the study, there were no overall significant differences. Within site years, compost application had an effect on plant and seed nutrient concentrations and uptake levels at all of the sites (Table 8) In general the annual applications were more effective than the single applications at increasing P uptake and P concentrations in the crop. The higher seed N concentrations in the untreated controls at the Elbow site, may be due to higher N fixation rates in the plants compared to those which received some N in the manure treatments. Pea was the test crop in the year after the treatments were applied. Rhizobial inoculants were applied at seeding so these crops should have been actively fixing N. In N deficient soils, N-fixation is stimulated compared to soils with high levels of plant available inorganic N. At the Elbow and Scott sites, the composted manure appears to have been a good source of P, resulting in higher plant P parameters.

TABLE 8. Effect of Compost Application on Plant and Seed Nutrient Levels at Elbow, Scott, and Vonda in Year 2.

	----------Elbow----------			---------Scott---------		Vonda
Treatment	Seed N	Seed P	Plant P	Plant P	Plant P Uptake	Seed N Uptake
t ha^{-1}	*mg g^{-1}*	*mg g^{-1}*	*mg g^{-1}*	*mg g^{-1}*	*kg ha^{-1}*	*kg ha^{-1}*
0 (a)	30.1a	2.33b	1.70c	1.67c	0.75b	48.8b
5 (a)	26.7c	2.64ab	1.95ab	1.90ab	0.87ab	59.8a
10 (a)	28.0bc	2.94a	2.06a	2.03a	1.06a	59.8a
10 (s)	28.1bc	2.70a	1.93ab	1.74bc	0.74b	48 9b
20 (s)	28.8ab	2.68a	1.83bc	2.00a	0.84b	53.3ab
LSD (P=.05)	1.7	0.33	0.17	0.2	0.2	7.2
CV	3.8	7.95	5.8	6.9	15.7	8.6

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

In contrast to the nutrient uptake measures, application of manure had no affect on yield parameters at Elbow, but did affect yield parameters at all of the other sites (Table 9). Total

biomass production and seed yield were increased in manure treated plants compared to controls at Scott and Vonda. Annual applications of the manure were superior to single applications.

TABLE 9. Result of Contrast Analysis of Biomass, Yield and Seed Weight at Elbow, Vonda, and Scott in Year 2.

BIOMASS

Location	Contrasts	Estimate	SE	t statistic	P > [t]
Scott	manure vs. no manure	763.3	308.2	2.48	0.0308
	annual vs. no manure	1013.3	330.5	3.07	0.0107
Vonda	manure vs. no manure	48.5	21.1	2.3	0.0401
	annual vs. no manure	23.5	23.1	3.18	0.0079
	annual vs. single	50	18.8	2.65	0.0211

YIELD

Location	Contrasts	Estimate	SE	t statistic	P > [t]
Scott	manure vs. no manure	143.1	45.8	3.12	0.0097
	annual vs. no manure	161.5	49.1	3.29	0.0073
	single year vs. no manure	124.7	49.1	2.54	0.0276
Vonda	manure vs. no manure	310.2	143.8	2.16	0.052
	annual vs. no manure	463.7	157.5	2.94	0.0123
	annual vs. single	307	128.6	2.39	0.0343

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Year 3:

No significant differences were observed in the overall analysis of the year 3 results. However within site years, compost application influenced P concentration and uptake levels in plant and seed at Elbow (Table 10). Year 3 had no additional compost added to any of the treatments (annual or single applications) and hence is a measure of the carryover effect from two annual applications or one single application. At the Elbow site there was a carryover effect of the P from the annual applications, and to a lesser degree the single applications.

TABLE 10. Effect of Compost Application on Phosphorous Concentration and Uptake at Elbow in Year 3.

	Seed		Plant	
Treatment $t\ ha^{-1}$	*P Conc* $mg\ g^{-1}$	*P Uptake* $kg\ ha^{-1}$	*P Conc* $mg\ g^{-1}$	*P Uptake* $kg\ ha^{-1}$
0 (a)	3.37c	4.36c	0.19c	0.62c
5 (a)	3.79ab	5.21abc	0.29ab	1.09ab
10 (a)	3.99a	6.11a	0.34a	1.34a
10 (s)	3.65abc	5.55ab	0.26bc	0.96bc
20 (s)	3.43bc	4.92bc	0.28ab	1.22ab
LSD (P=.05)	2.2	1.14	0.07	0.34
CV	7.1	14.17	17.37	21.05

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

At the Scott location, compost treatment had an effect on biomass and yield production in year three of the study, although the reason for the effects are not clear. In year 3 at this site, the

smallest application rate (5t ha^{-1}) had the largest carry-over effect. Both total biomass and seed yield were highest in this treatment, followed by a single application of the highest manure rate (20 t ha^{-1}).

TABLE 11. Effect of Compost Treatment on Biomass and Yield at Scott in Year 3.

Treatment	Biomass	Yield
t ha^{-1}	*kg ha^{-1}*	
0 (a)	4310c	1329.7c
5 (a)	6160a	1818.0a
10 (a)	4690bc	1599.5ab
10 (s)	4545bc	1523.1bc
20 (s)	5785ab	1731.5ab
LSD (P=.05)	1392.2	241.1
CV	17.7	9.8

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

In summary, the application of composted manure was effective in increasing plant P uptake and tissue concentrations, as well as total biomass production and yield at all of the sites except the adequately fertile Kernen site. In general, annual applications were more effective than single applications, although there was carry-over of the single applications into subsequent years. Because manure has a higher ratio of P:N than plant tissues, there is risk of excessive build-up of P in the soil with over application of manures. However, because of the lack of inorganic fertilizer applications on organic farms, this risk would be very small in an organic system. In a situation where a lot of manure is available for field application, producers should apply it at rates based on the P content rather than the N content.

3.3 Experiment 3. Evaluation of Annual Green Manure Crops on Soil Fertility and Weed Populations.

Objective

This experiment examined the effect of annual green manure crops on soil fertility levels, weed population control, and crop rotation under organic cropping systems. Green manure crops were selected for nitrogen fixation ability, alleleopathic characteristics, and influence on soil phosphorous availability.

Materials and Methods

Trials were conducted at Vonda, Elbow, Scott, and Kernen in the black, brown, and dark brown soil zones, respectively from 2002 to 2005. The experimental design was a RCBD with four replicates. Six different annual green manure crops were studied in this trial (Table 12). The buckwheat and oilseed radish are non-legumes that reportedly increase P-solubilization. Two incorporation dates were used; early (before July 11) and late (before Aug 1). At the initiation of the experiment soil tests were performed to determine pre-treatment fertility levels (Table 13). Plant density, weed population density, crop biomass dry weight, weed biomass dry weight, plant nutrient content, and soil moisture data were collected throughout the growing season. Plant and weed density counts were recorded approximately one month after seeding, using 1/4m^2 quadrants (50cm x 50cm) at the front and back of each plot. Biomass samples were collected at 9 (early) and 12 (late) weeks, using 1/4m^2 quadrants at the front and back of each

plot. Samples were dried in a drying oven at 70 °C for a 48 hour period. All samples were averaged for each plot.

Due to drought conditions, data was not collected from the site at Elbow in 2002 and 2003. Attempts at crop establishment were unsuccessful in both years of the trial.

Plant density, weed density, and biomass data (early incorporation dates only) were collected before the trial was terminated at Vonda in 2002. Crop establishment was successful in 2003 at this location. Incorporation of green manure crops was implemented and the trial was recropped to wheat (AC Barrie) in 2004.

Crop establishment was successful at the Scott location in 2002, and green manure crops were incorporated. In 2003 the trial was recropped to wheat. Yield and soil moisture data were monitored and collected throughout the growing season.

The Kernen location was established in 2004, with successful green manure establishment and incorporation. This site was recropped to AC Elsa wheat (250 pl m^{-2}) in 2005.

TABLE 12. Green Manure Crops, Varieties and Seeding Rates.

CROP	VARIETY	SEEDING RATE *kg ha^{-1}*
BUCKWHEAT	*Mancan*	82
CHICKLING VETCH	*AC Greenfix*	100
FENUGREEK	*CDC Quatro*	34
BLACK LENTIL	*Indianhead*	43
ALFALFA	*Nitro*	15
OILSEED RADISH	*Oleiferus*	14

TABLE 13. Initial Soil Analysis for Annual Green Manure Trial.

	Location/Year						
Soil Property	**Vonda**	**Scott**	**Elbow**	**Vonda**	**Elbow**	**Vonda**	**Kernen**
	2002	2002	2002	2003	2003	2004	2004
Nitrogen (NO_3-N)	25.8	34.9	18.1	22	17	28	107
Phosphorus (P_2O_5-P)	6.2	7.1	5.9	14	24	37	65
Potassium (K)	357.7	310.8	127.4	779	724	964	1200
Sulfur (SO_4-S)	7.5	7	8	29	33	59	41
pH levels	6.8	5.8	7.4	7.7	8.0	7.0	7.9

Nutrient levels in lb/acre

Results and Discussion

There were no significant differences in overall crop and weed biomass production in the green manure incorporation year. However, the legume crops produced an average of 938 kg ha^{-1} less biomass than the non-legume crops (Table 14). The legume crops also proved to be significantly less competitive with weeds than their non-legume counterparts, yielding on average 497 kg ha^{-1} more weed biomass.

TABLE 14. Summary of Crop and Weed Biomass in the Incorporation Year of Annual Green Manure Trial averaged over all site years.

	Biomass *kg ha^{-1}*	
Crop	**Crop**	**Weed**
Oilseed Radish	2028.98	627.29
Buckwheat	1281.96	1059.54
Lentil	1057.7	1010.59
Chickling Vetch	943.62	1228.65
Fenugreek	613.58	1470.95
Nitro Alfalfa	254.95	1651.62

Contrasts	Estimate	SE	DF	t statistic	P > [t]
Crop Biomass (*kg ha^{-1}*)					
legumes vs. non legumes	-938.00	396	10.4	-2.37	0.039
Weed Biomass (*kg ha^{-1}*)					
legumes vs. non legumes	497.04	215	10.9	2.31	0.042

Site year had a significant effect on green manure crop production. Within site years there were many differences between crop and weed biomass production (Table 15). Fenugreek and alfalfa had consistently poor productivity and weed suppression. Therefore, they are unsuitable as green manure crops. Buckwheat production was moderate but tended to struggle under low fertility and poor moisture situations. Buckwheat does not fix N and probably suffered from the low N conditions at Vonda. Oilseed radish was difficult to establish, likely due to the fact that is it a cool season crop. However when there was a good catch, it yielded extremely well and provided excellent weed suppression.

TABLE 15. Summary of Crop and Weed Biomass Data at Vonda, Scott, and Kernen

	Vonda 2002		Vonda 2003		Kernen 2004		Scott 2002	
	Biomass *kg ha^{-1}*							
Crop	Crop	Weed	Crop	Weed	Crop	Weed	Crop	Weed
Buckwheat	462.8a	224.0b	254.5b	1444.5a	2212.5b	1359.3b	1062.8a	0.0b
Chickling vetch	184.8b	434.0a	168.5bc	1636.3a	1786.5bc	1496.3ab	503.4c	7.6b
Fenugreek	23.8d	481.0a	65.1cd	1584.8a	1186.0cd	2071.5ab	330.5c	0.0b
Indianhead Lentil	120.8bc	382.8ab	757.8a	1340.5a	1777.0bc	1360.0b	371.5c	1.9b
Nitro Alfalfa	34.3cd	519.3a	48.3d	1688.8a	617.5d	2387.3a	0.0d	198.3a
Oilseed radish	164.5b	241.5b	104.3cd	1620.3a	4685.3a	147.5c	724.7b	0.0b
LSD (P=.05)	777.8	895.2	198.2	102.2	106.5	504.5	96.4	165.7
CV	37.5	60.0	26.8	198.7	45.0	32.0	39.3	29.3

*Site years were analyzed separately

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Green manure treatment had a significant influence on wheat yield in the recrop year of this study (Table 16). The oilseed radish treatment yielded lower than the other treatments, likely due to water usage and no addition of fixed N. If non-legume green manures are to be used to target P-fertility in organic systems, they will need to be intercropped with a legume to provide both P and N, if possible. There was also a problem with volunteer plants in the recrop

year at some of the sites which reduced the yield of the recrop. The legume treatments produced significantly more yield than non-legume treatments, averaging an increase of 108 kg ha^{-1}.

TABLE 16. Wheat Yield the Year Following Different Annual Green Manure Crops Averaged Over All Site Years

Treatment	**Yield** *kg* ha^{-1}
Indianhead lentil	1760.26a
Nitro alfalfa	1757.33a
Fenugreek	1718.55a
Chickling vetch	1713.23a
Buckwheat	1678.99a
Oilseed radish	1545.26b

Contrasts	Estimate	SE	DF	t statistic	P > [t]
Wheat Yield					
legumes vs. non legumes	108.69	62.18	11	1.75	0.109

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Wheat yield following the green manure crops differed depending on both the timing of the incorporation and the green manure (Figure 1). With the exception of fenugreek, green manures incorporated early produced higher wheat yields the subsequent year than green manures incorporated late. This is probably the result of less moisture being depleted by the earlier ploughdown crop. There was no difference in wheat biomass following the fenugreek ploughdowns incorporated at different times.

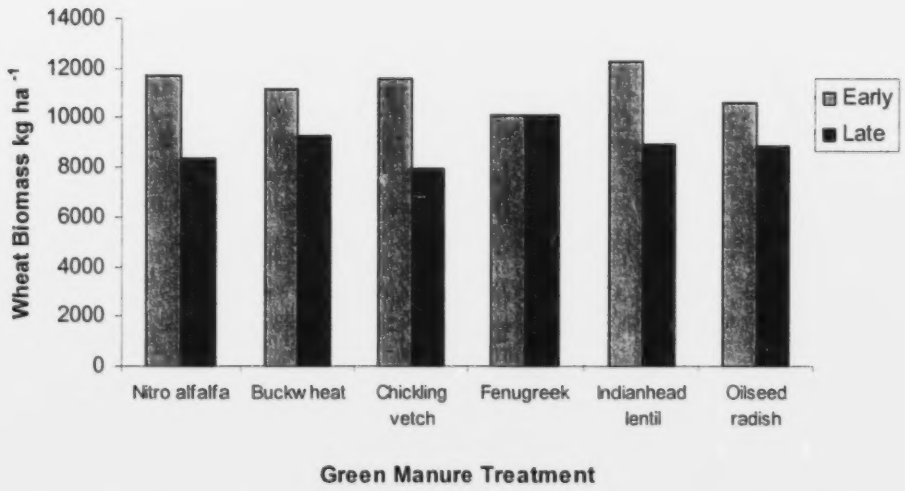

FIGURE 1. The effect of early and late incorporation of green manure crops on wheat biomass in the subsequent growing season.

Time of incorporation also had an effect on weed biomass in the wheat crop. The late incorporation date resulted in 385.9 kg ha^{-1} less weed biomass then the early incorporation date in the recrop year. Lower weed biomass production from the early to late incorporation

treatments is likely a result of moisture usage by the green manure crops in the previous year. The green manure crops grown longer used more water, which served to control some of the weeds.

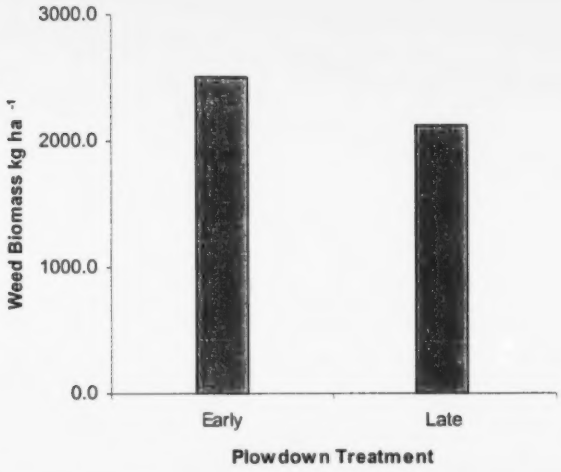

FIGURE 2. Effect of green manure incorporation date on weed biomass in a subsequent year.

Time of incorporation was the only significant treatment when the sites were analyzed separately (Table 17). At Kernen, the early incorporation treatments averaged 3677 kg ha^{-1} more crop biomass than the late incorporation treatments. Time of incorporation had an effect on yield, as well as crop and weed biomass at Vonda. The late incorporation treatments had 1016.1 kg ha^{-1} less crop and 336.6 kg ha^{-1} less weed biomass than the early incorporation treatments. Average yield was also decreased by 682.3 kg ha^{-1} due to late incorporation. These differences are likely a result of moisture usage from the green manure crops in previous year. Since the late incorporation treatments had a prolonged growing season, they undoubtedly had greater moisture requirements than the early incorporation equivalents.

TABLE 17. Summary of Wheat Biomass and Yield Data from Kernen (2005) and Vonda (2004). All values are in kg ha^{-1}.

	Vonda 2004			Kernen 2005		
	Biomass			Biomass		
Plowdown	Crop	Weed	Yield	Crop	Weed	Yield
Early	4556.3a	876.9a	2118.7a	17895.0a	4144.5a	1894.3a
Late	3540.2b	540.3b	1436.4b	14218.0b	3759.9a	1664.1a
LSD (P=.05)	541.8	199.6	214.9	2071.0	1204.6	236.7
CV	22.9	48.1	20.7	19.8	46.9	20.2

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

There were no overall differences among green manure treatments in terms of the N and P nutrient status of the subsequent wheat crop (data not shown).

There were differences among the incorporation dates in terms of the N and P uptake by the wheat crop at Vonda and Kernen (Table 18 and 19). The amount of biomass incorporated into the soil at the time of ploughdown was similar for the two incorporation dates (data not shown). Consistent with the higher yields observed in wheat grown on the early incorporated crops, N and P uptake were also higher (Table 18 and 19). Phosphorous in particular is translocated into seed storage (high P uptake based on seed values), whereas N is more balanced between the seed and other tissues. The higher N concentrations observed in wheat grown on the early incorporated green manure crops may be a result of the younger tissues incorporated at the first incorporation date being more easily decomposed. The N in the biomass may be more easily mineralized and available for the subsequent crop. The higher amount of moisture left in the soil with the first incorporation date would also contribute to higher decomposition rates. However, this does not explain the higher wheat tissue P concentrations observed in the crop grown on the later incorporated green manure crops.

Somewhat surprisingly, at Kernen, N concentration in the tissues was slightly but significantly higher in wheat grown on non-legume green manures than wheat grown on the legumes green manures (Table 18). This site had fairly high soil N concentrations at the onset of the experiment (Table 13). The legume crops at this site were probably not relying on biological N fixation for their N supply. The difference between the N concentrations in the wheat is probably a result of the non-legume crops being slightly more effective at redistributing the N in the soil probably because of differences in the root systems.

At the Vonda site the lentil green manure was superior to the others in terms of the subsequent N uptake by the wheat crop (Table 18). In a study related to this study Lawley (2005) found Indianhead lentil grown as a green manure crop to have a higher proportion nitrogen than chickling vetch or field pea. It did not necessarily produce as much biomass as the other crops but on a tissue weight basis it accumulated more N.

TABLE 18. Plant Nitrogen and Phosphorous Concentrations and Uptake at Vonda and Kernen in Wheat in Year 2 of the rotation

	Vonda			Kernen	
Treatment	*N Conc* $mg\ g^{-1}$	*P Conc* $mg\ g^{-1}$	*N Uptake* $kg\ ha^{-1}$	*N Conc* $mg\ g^{-1}$	*N Uptake* $kg\ ha^{-1}$
early	12.4a	1.45b	56.3a	7.51a	135.1a
late	9.8b	1.81a	34.3b	5.52b	78.3b
LSD (P=.05)	1.32	0.22	7.52	1.02	22.03
CV	20.4	23.4	28.4	23.9	31.4

Contrasts	Estimate	SE	t statistic	P > [t]
Kernen N Conc				
legumes vs. non legumes	-1.13	0.535	-2.12	0.0434
Vonda N Uptake				
lentil vs. all others	11.1	4.98	2.23	0.032

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

TABLE 19. Seed Nitrogen and Phosphorous Concentrations and Uptake at Vonda and Kernen in Wheat in Year 2 of the rotation.

	Vonda			Kernen	
Treatment	*P Conc* $mg\ g^{-1}$	*P Uptake* $kg\ ha^{-1}$	*N Uptake* $kg\ ha^{-1}$	*N Conc* $mg\ g^{-1}$	*N Uptake* $kg\ ha^{-1}$
early	4.02b	8.48a	38.4a	27.0a	51.2a
late	4.24a	6.04b	25.3b	25.9b	42.9b
LSD (P=.05)	0.15	0.87	3.60	0.92	6.49
CV	5.9	20.2	19.0	5.3	20.9

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

3.4 Experiment 4. Evaluation of Annual and Perennial Green Manure Crops on Soil Fertility and Weed Populations.

Objective

The objective of this experiment is to evaluate the effectiveness of green manure crops on soil fertility and weed control in an organic crop rotation. The study focused on annual and perennial crop species, as well as spring seeded and fall seeded crops, and their effects on weed populations and soil fertility in subsequent crops. This study differed from experiment 4 in that it directly compared annual green manure crops to perennial green manure crops. As the perennial green manure crops required one extra year to establish they had to be compared to annual green manure crops in a separate experiment.

Materials and Methods

This experiment was located at Elbow, Scott, and Vonda. The experimental design was a RCBD with four replicates. During the initiation year, plots were seeded to wheat at a target density of 250 plants m^{-2}, with the exception of the sweet clover plots. These plots were seeded to 1/3 rate of wheat and under seeded to sweet clover in Elbow and Vonda. At the Scott location, sweet clover was sown with 10 inch row spacing into alternating rows of wheat. Fall rye was sown in the fall at the Scott location and in the early spring at the Vonda and Elbow locations. Eight green manure crops were studied in this trial (Table 20). Two incorporation dates were used; early (before July 11) and late (before Aug 1). Soil tests were taken prior to seeding at all locations to determine existing fertility levels (Table 21). Plant density, weed population density, crop biomass dry weight, weed biomass dry weight, plant nutrient content, and soil moisture data were collected. Plant and weed density counts were recorded approximately one month after seeding, using $1/4m^2$ quadrants (50cm x 50cm) at the front and back of each plot. Biomass samples were collected at 9 (early) and 12 (late) weeks, using $1/4m^2$ quadrants at the front and back of each plot. Samples were dried in a drying oven at 70 °C for a 48 hour period. All samples were averaged to provide values for each plot.

Due to drought conditions in 2002, crop establishment at the Vonda and Elbow locations was unsuccessful. In 2003, growing conditions were more favourable and the sweet clover plots were established. Annual crops were sown in 2004 at these locations, and incorporation dates were implemented throughout the growing season. The trials were recropped in 2005 to AC Elsa wheat. The Scott location was established in 2002; the annual green manure crops were sown in spring 2003. Crop and weed biomass data was collected and soil moisture data was monitored

throughout the growing season. Biomass samples were collected at 9 weeks, using $1/4m^2$ quadrants at the front and back of each plot. Samples were dried in a drying oven at 70 ºC for a 48 hour period. All samples were averaged to provide values for each plot.

TABLE 20. Green Manure Crops, Varieties, and Seeding Rates.

CROP	VARIETY	SEEDING RATE *kg ha^{-1}*
BUCKWHEAT	*Mancan*	82
CHICKLING VETCH	*AC Greenfix*	100
FENUGREEK	*CDC Quatro*	34
SWEET CLOVER	*Yukon*	8
FALL RYE	Common #1	90
BLACK LENTIL	*Indianhead*	43
ALFALFA	*Nitro*	15
OILSEED RADISH	*Oleiferus*	14

TABLE 21. Pre-treatment Soil Nutrient Analysis for Green Manure Trial

	Location/Year		
Soil property	**Vonda**	**Scott**	**Elbow**
	2004	2003	2004
Nitrogen (NO_3-N)	28	34.9	17
Phosphorus (P_2O_5-P)	37	7.1	24
Potassium (K)	964	310.8	724
Sulfur (SO_4-S)	59	7	33
pH levels	7.0	5.8	8.0

Nutrients are in lb/acre

Results and Discussion

Green manure treatment had a significant overall effect on crop biomass (Table 22). Sweet clover produced significantly more biomass than the rest of the treatments. The perennial crops also significantly out produced the annual crops by 3359.3 kg ha^{-1}. Time of incorporation had no effect on biomass production, implying that early incorporation is as good as late. Management of green manure plowdowns involves a balancing act between biomass production and soil moisture usage. Because there were no differences in biomass production between early and late incorporation dates, early incorporation is recommended as a means of conserving water.

TABLE 22. Crop and Weed Biomass Production of Green Manure Crops averaged over all locations

	Biomass *kg ha^{-1}*			
Treatment	**Crop**		**Weed**	
Sweet clover	6507.1	a	224.6	c
Fall rye	2610.5	b	159.5	c
Oilseed radish	1887.3	b	401.3	bc
Indianhead lentil	1649.9	b	528.4	ab
Chickling vetch	1214.7	b	709.1	ab
Buckwheat	965.2	b	784.5	ab
Fenugreek	780.3	b	871.6	a
Nitro alfalfa	699.5	b	913.1	a

Contrasts	Estimate	SE	DF	t statistic	P > [t]
Crop Biomass					
sweet clover vs. all others	4467.74	663	16.6	6.74	<.0001
perennial vs. annual	3359.29	579	16.6	5.8	<.0001
Weed Biomass					
sweet clover vs. all others	-349.4	150.72	12.5	-2.32	0.0381
perennial vs. annual	-509.3	130.59	12.4	-3.90	0.0020

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Green manure treatment significantly affected overall weed biomass. Sweet clover and fall rye were better at suppressing weeds than the rest of the crops, with the exception of oilseed radish. Sweet clover reduced weed biomass by 349.4 kg ha-1 when compared to the rest of the crops. On average, the perennial crops suppressed weed growth by 509.3 kg ha-1 in comparison with the annual crops. Fenugreek and Nitro alfalfa displayed poor weed suppression because of their inability to ever successfully establish, and are therefore unsuitable as green manure crops in organic production.

An interaction between year, location, and crop was observed in the overall analysis for crop biomass, indicating that the crops performed differently depending on site year and location. The biomass data from each site year is summarized in Table 23. Fenugreek and alfalfa had consistently poor productivity and weed suppression in all site years, proving to be unsuitable as green manure crops. Buckwheat production was moderate but tended to struggle under low fertility and poor moisture situations. Oilseed radish also grew poorly when fertility and moisture conditions were very poor. However when there was a good catch, it yielded extremely well and provided good weed suppression. In keeping with the previous experiment, these two crops are not leguminous and probably suffer from the low N fertility inherent to organic farms. Thus as green manure crops they have the paradoxical requirement of requiring high N fertility for successful growth.

TABLE 23. Crop and Weed Biomass Data from Vonda, Scott, and Elbow

	Vonda 2004		Elbow 2004		Scott 2003		Scott 2004	
	Biomass							
Crop	*kg ha^{-1}*							
	Crop	Weed	Crop	Weed	Crop	Weed	Crop	Weed
Sweet clover	8626.0a	4.5d	6010.0a	39.5b	6323.3a	309.6dc	2251.3a	540.0abc
Fall rye	2278.5b	475.5cd	592.5b	307.5b	5514.3a	56.9d	2555.0a	12.5c
Oilseed radish	1534.8c	500.5bcd	389.3b	669.2a	2594.5b	173.9cd	2268.4a	200.0
Indianhead lentil	2192.0b	594.3bc	325.8b	732.5a	1792.6bc	223.8cd	1057.5b	572.5
Chickling vetch	932.3cd	1023ab	433.5b	652.3a	1631.8c	362.1dc	742.5bcd	820.0
Buckwheat	113.5e	1364a	45.5b	633.3a	1779.8bc	480.5bc	925.0bc	720.0
Fenugreek	405.3de	1247a	85.0b	628.8a	1036.9cd	756.0ab	492.5cd	942.5
Nitro alfalfa	585.5de	1154a	44.8b	816.0a	637.5d	922.4a	310.0d	832.5
LSD (P=.05)	618	542	551.4	318	961	364	517.6	568
CV	34	54.9	73.9	45.8	35.9	88.1	35.8	93.1

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

A crop by time of incorporation interaction on wheat yield was observed in the recrop year of this study (Figure 3). The late incorporation treatments of sweet clover and fall rye produced significantly less yield than the late incorporation treatments of alfalfa and buckwheat. Although the sweet clover and fall rye had very good weed suppression, the moisture usage to attain that suppression was detrimental to subsequent crop yield. Therefore, early incorporation of green manure crops, particularly sweet clover and fall rye is highly recommended.

Type of green manure crop and time of incorporation had no overall effect on crop or weed biomass in the subsequent year of crop rotation.

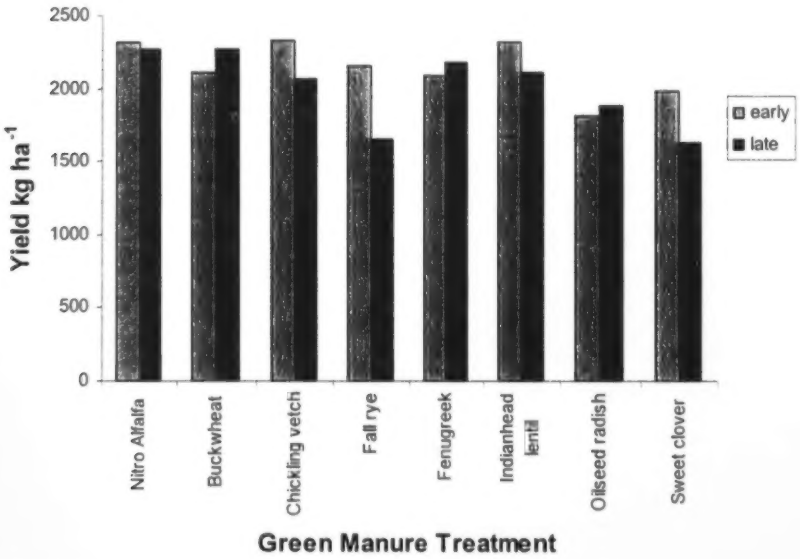

FIGURE 3. Effect of green manure treatment and time of incorporation on wheat yield in a subsequent year.

Scott was the only location where green manure treatment had an effect on yield when the site years were analyzed separately. The oilseed radish, sweet clover, and fall rye treatments had significantly lower wheat yield than the rest of the green manure crops (Table 24). This decrease in yield is likely due to moisture usage.

TABLE 24. Effect of Green Manure Treatment on Wheat Yield at Scott 2004.

Green Manure Treatment	**Yield** *kg ha^{-1}*
Alfalfa	3054.6a
Buckwheat	2916.5a
Chickling vetch	2902.4a
Lentil	2848.6a
Fenugreek	2742.4a
Oilseed radish	2328.3b
Fall rye	2239.5b
Sweet clover	2046.2b
LSD (P=.05)	353.76
CV	13.35

Differences in N and P concentrations and/or uptake were observed among the individual green manures (Table 25) at Elbow and Vonda. N uptake values include N extracted from the soil, as well as biological N fixation in the legume crops. At Elbow, of the annual green manures, oilseed radish was superior to the others in extracting P from the soils. At Vonda, oilseed radish was second to Indianhead lentil. There is evidence that legumes form very effective mycorrhizal associations that aid in uptake of P and other nutrients. In addition there have been reports of Rhizobium bacteria have a dual ability to solubilize P along with their symbiotic N-fixing ability. The chickling vetch, lentil and sweet clover were quite effective at extracting P from the soil, and were superior to buckwheat which was grown specifically for its ability to extract P from the soil. For organic producers, it does not appear to be necessary to grow green manures other that legumes, that are specifically aimed at solubilizing P. Although the oilseed radish was also extremely good at taking up N from the soil, it would not be advisable to use as a frequently used green manure, because all of the N in the tissue originates from soil N. There is no atmospheric contribution, because this crop in not leguminous. Similarly, fall rye performed well in terms of both N and P uptake, but again does not add atmospheric N to the system. Fall rye is usually included in rotation because of its allelopathic attributes for suppressing weeds. Overall, in this study it performed well in terms of weed suppression (Table 22) and should be considered as part of a weed control strategy by organic producers, recognizing that in terms of soil fertility it is very effective at redistributing nutrients but does not add nutrients to the system.

Table 25 . Plant Nitrogen and Phosphorous Concentrations and Uptake in Green Manure crops at Vonda and Elbow in Year 1 of the Rotation.

	Elbow			Vonda			
Treatment	*P Conc* $mg\ g^{-1}$	*N Uptake* $kg\ ha^{-1}$	*P Uptake* $kg\ ha^{-1}$	*N Conc* $mg\ g^{-1}$	*P Conc* $mg\ g^{-1}$	*N Uptake* $kg\ ha^{-1}$	*P Uptake* $kg\ ha^{-1}$
Sweet clover	1.44d	137.81a	8.94a	~	~	~	~
Fall rye	2.33bc	9.95b	1.39b	~	~	~	~
Oilseed radish	3.31a	6.93b	1.28b	10.04d	2.87c	21.88c	6.14b
Indianhead lentil	2.70b	6.99b	0.93b	30.76a	2.81c	111.03a	10.13a
Chickling vetch	2.62b	9.77b	1.10b	32.72a	2.97bc	50.05b	4.60bc
Buckwheat	2.75b	0.80b	0.12b	18.39c	3.75a	1.44d	0.35d
Fenugreek	2.13c	1.74b	0.21b	24.17b	3.47ab	14.19cd	1.94d
Nitro alfalfa	2.41bc	0.98b	0.11b	31.11a	2.50c	30.02c	2.38cd
LSD (P=.05)	0.45	20.25	1.46	3.33	0.59	19.22	2.37
CV	15.7	124.3	101.7	9.2	13.1	33.9	37.5

In the wheat crop grown in the year following the green manure incorporation, none of the differences in P uptake observed for the green manures were evident in the wheat. There were small but significant differences in N concentrations in wheat leaf and stem tissues (Plant N) at Elbow and seed N at Vonda (Table 26). The perennial green manures were superior to the annual green manures at supplying N to the wheat crop at Vonda and Elbow. Sweet clover in particular was better than all of the other green manures for its ability to supply N. However at Vonda, sweet clover was inferior to the other green manures at supplying P. There was not difference for P at the other sites.

TABLE 26. Plant and Seed Nitrogen Concentrations at Elbow and Vonda in Wheat grown in Year 2 of the Rotation.

	Elbow	**Vonda**
Treatment	*Plant N Conc* $mg\ g^{-1}$	*Seed N Conc* $mg\ g^{-1}$
Sweet clover	3.35ab	2.37a
Fall rye	3.78a	2.03c
Oilseed radish	2.89b	2.11bc
Indianhead lentil	3.24ab	2.14bc
Chickling vetch	2.88b	2.11bc
Buckwheat	2.79b	2.03bc
Fenugreek	3.07b	2.03c
Nitro alfalfa	3.03b	2.16b
LSD (P=.05)	0.58	0.13
CV	18.47	6.05

Plant Nutrient Concentration & Uptake

Contrasts	Estimate	SE	t statistic	P > [t]
Elbow N Conc				
perennial vs. annual	0.58	0.167	3.5	0.001
Elbow N Uptake				
perennial vs. annual	5.87	2.514	2.34	0.0237
Vonda P Conc				
sweet clover vs. others	-0.34	0.153	-2.24	0.0298
Vonda N Uptake				
sweet clover vs. others	4.69	1.615	2.91	0.0055

Seed Nutrient Concentration & Uptake

Contrasts	Estimate	SE	t statistic	P > [t]
Vonda N Conc				
perennial vs. annual	2.44	0.425	5.76	<.0001
sweet clover vs. others	1.01	0.371	2.71	0.0093
Vonda N Uptake				
sweet clover vs. others	3.93	1.68	2.33	0.0238

An interaction between incorporation date and green manure treatment on N concentration (Figure 4) and N uptake (Figure 5) in wheat grown in the subsequent year was observed at the Elbow site and to a lesser degree at the Vonda site (data not shown). Wheat grown after fall rye that was incorporated early, had higher N concentrations and N uptake than wheat grown on fall rye incorporated late. With the exception of the nitro alfalfa, all of the other green manure crops resulted in higher N concentration and uptake at the later incorporation date than the earlier. Despite this, because of the effects on soil water as well as weed suppression, it is recommended to incorporate a green manure crop earlier rather than later.

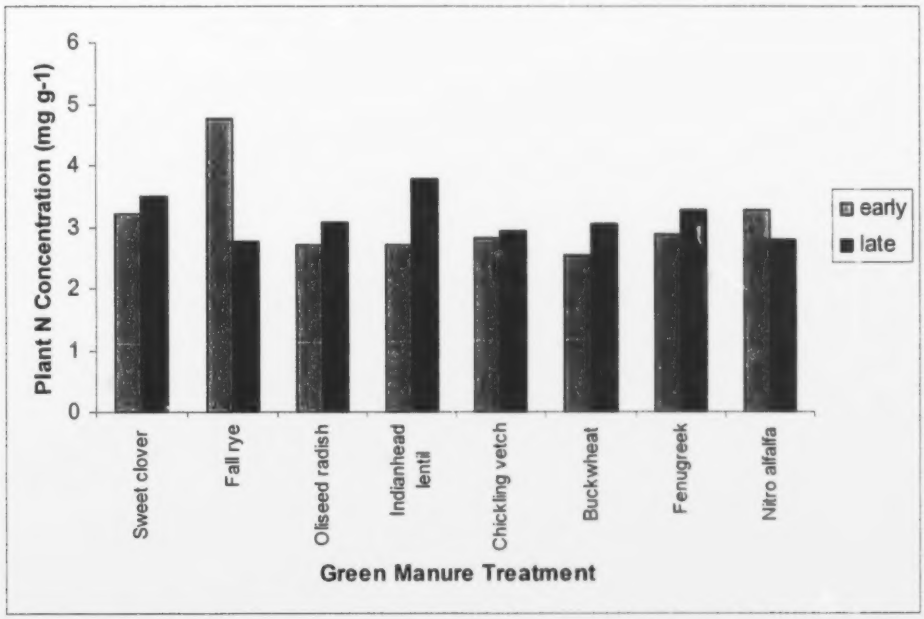

FIGURE 4. Interaction between green manure treatment and incorporation date on Plant N concentration in wheat at Elbow.

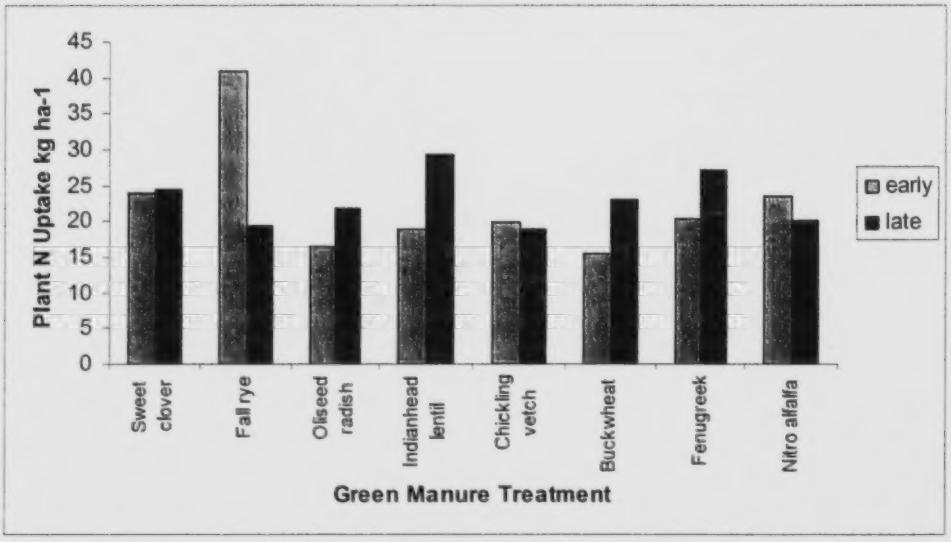

FIGURE 5. Interaction between green manure treatment and incorporation date on Plant N uptake by wheat at Elbow.

In summary, based on the results of the two green manure experiments we can make some general recommendations regarding the use of green manures in organic systems. Regardless of the green manure crop early incorporation is recommended to conserve soil water resources. There may be some exceptions in especially wet areas of the province. Generally speaking sweetclover was the best green manure for supplying N and P. Again use of this crop will be site dependent since it is a biannual crop and can cause soil drying. Producers in the brown soil zone tend to be reluctant to grow sweet clover because of its water demands. A potential solution (although untested in this research project) to the water use problems associated with a sweet clover green manure crop may be very early termination. This would prevent excess water use and allow more time for the soil to recharge. Of the annual green manures tested Indianhead lentil performed fairly well in terms of its N and P contribution to the subsequent crop. It also had moderate weed suppression at most of the sites. Oilseed radish and fall also performed well for supplying nutrients as well as controlling weeds, but because they are non-leguminous they not add N to the system. It was also difficult to source seed for the oilseed radish. Both of these crops may have a place in organic management systems, particularly for weed control. Most of the legumes (except nitro alfalfa) fixed N and thus adding N to the system, were quite effective at solubilizing P. It appears to be unnecessary to grow non-leguminous crops such as buckwheat (which performed poorly) specifically for P solubilization, as the legumes were able to perform this function.

3.5 Experiment 5. Cereal variety trial: A Comparison of Modern, Low Input, and Heritage Varieties.

Objective

This experiment was a comparative study examining modern, low input, and heritage cereal varieties in organic crop production. Modern crop cultivars have been selected under conditions which may favour them in high input conventional agriculture systems. Thus, there suitability for use in organic systems is questionable with respect to weed competitiveness and management regimes practiced in organic agriculture. In contrast, genotypes selected for low input agriculture and heritage varieties have not had selection pressure under high input systems and may be better suited towards use in organic agriculture.

Materials and Methods

This experiment was conducted at Elbow, Vonda, Scott, and Kernen, in the brown, thin black, and dark brown soil zones, respectively fro 2002 to 2005. Trials were seeded as a four replicate RCBD, blocked into crop type. Soil tests were conducted prior to seeding (Table 27). Four different cereal types were examined in this experiment; wheat, durum, oats, and barley (Table 28). The genotypes were chosen in consultation with plant breeders with the CDC. We attempted to select representative heritage and modern cultivars for all the crop types. For barely and oat genotypes which had characteristics that were believed to made them suitable for low input agriculture were also selected. Each crop was seeded at a density of 250 plants m^{-2} at 8 or 10 inch row spacing. The experiment was conducted on cereal stubble at all locations. All sites were tilled prior to seeding. Post emergent harrowing with a flex-tine harrow was used to control early flushes of weeds at all sites. Plant density, biomass dry weight, and weed density data was collected throughout the growing season. Plant and weed density counts were recorded approximately one month after seeding, using $1/4m^2$ quadrants (50cm x 50cm) at the front and back of each plot. Biomass samples were collected at 12 weeks, using $1/4m^2$ quadrants at the front and back of each plot. Samples were dried in a drying oven at 70 °C for a 48 hour period. All samples were averaged to provide values for each plot.

In 2002, due to drought conditions and grasshopper infestation, none of the trial sites were harvested. In 2003, the sites at Vonda and Elbow (oats only) were brought to harvest. All sites, Vonda, Scott, and Kernen, were harvested in 2004 and 2005.

TABLE 27. Soil Nutrient Analysis for Cereal Variety Trial

	Year/Location						
Soil Property	*2002*			*2003*		*2004*	
	Vonda	**Scott**	**Elbow**	**Vonda**	**Elbow**	**Vonda**	**Kernen**
Nitrogen (NO_3-N)	34.5	34.9	20.4	22	17	17	107
Phosphorus (P_2O_5-P)	6.2	7.1	5.4	14	24	14	65
Potassium (K)	339.0	310.8	120.8	779	724	666	1200
Sulfur (SO_4-S)	7.4	7.0	5.4	29	33	96	41
pH levels	6.9	5.8	7.4	7.7	8	7.9	7.9

TABLE 28. Description of Crop Varieties.

VARIETY	CROP	YEAR	DESCRIPTION
AC BARRIE	wheat	1994	CWRS
AC SUPERB	wheat	2000	CWRS
APEX	wheat	1937	CWRS
LEE	wheat	1951	CWRS
MARQUIS	wheat	1910	CWRS
RED BOBS	wheat	1926	CWRS
RED FIFE	wheat	1885	CWRS
THATCHER	wheat	1935	CWRS
AC AVONLEA	durum	1997	CW Amber Durum
KYLE	durum	1984	CW Amber Durum
PELISSIER	durum	1929	CW Amber Durum
PLENTY	durum	1990	CW Amber Durum
SCEPTRE	durum	1985	CW Amber Durum
AC ASSINIBOIA	oats	1995	General purpose oat
AC MORGAN	oats	1999	General purpose oat
CALIBRE	oats	1983	General purpose oat
CDC DANCER	oats	2000	General purpose oat
GARRY	oats	1948	General purpose oat
HARMON	oats	1965	General purpose oat
SA98084	oats	nr	General purpose oat
SA98511	oats	nr	General purpose oat
VICTORY	oats	1908	General purpose oat
BETZES	barley	1960	2-row hulled barley
CDC COPELAND	barley	1999	2-row hulled barley
CDC DOLLY	barley	1999	2-row hulled barley
CDC MCGWIRE	barley	1999	2-row hulless barley
CONQUEST	barley	1965	6-row hulled barley
HANNCHEN	barley	1908	2-row hulled barley
HB353	barley	nr	hulless barley
HUSKEY	barley	1953	6-row hulled barley
MANLEY	barley	1990	2-row hulled barley
OAC 21	barley	1910	6-row hulled barley
SB97590	barley	nr	hulled barley
SB98340	barley	nr	hulled barley
SCOUT	barley	1982	2-row hulless barley
SH97088	barley	nr	hulless barley
TUPPER	barley	1984	6-row hulless barley

[nr]variety is currently not registered

Results and Discussion

Wheat variety had no overall significance differences in yield when averaged over all site years (Table 29). However, in contrasting Red Fife against all other wheat varieties, Red Fife produced 156.4 kg ha^{-1} more yield than the others.

TABLE 29. Wheat Yield Data from Cereal Variety Trial.

Variety	Yield *kg ha^{-1}*
Red Fife	1412.9
Superb	1341.0
Lee	1295.1
Red Bobs	1278.9
Barrie	1266.4
Marquis	1259.2
Thatcher	1212.6
Apex	1142.3

Contrasts	Estimate	SE	DF	t statistic	P > |t|
Red fife vs. all others	156.4	71.9	35	2.17	0.037

Within site years, Red Fife did consistently well (Table 30). However, Red Fife was observed to mature later than the other varieties and in at least one location suffered frost damage. AC Superb yielded very well at Kernen in 2004, likely due high soil N levels. This site was broken from a well established alfalfa crop, and although it had been seeded to wheat the year prior to experimentation, the soil N levels were very high (Table 27). Since AC Superb is a modern variety, we believe it was adapted to do well under these high nutrient conditions. Apex had consistently lower yields across all site years, and is not recommended in organic production.

TABLE 30. Wheat Yield Data from Kernen, Vonda, and Scott

	Kernen		Vonda			Scott
	2004	2005	2003	2004	2005	2004
	kg ha^{-1}					
Red Fife	2142.3b	1168.9a	967.8a	1236.9	1045.3a	1915.9
Barrie	2059.4b	934.0bc	686.1e	1052.1	913.9ab	1953.1
Lee	1886.7b	901.5bc	910.4ab	1166.4	912.0b	1993.6
Marquis	1765.9b	999.5ab	833.7bc	1206.6	913.5ab	1835.7
Superb	2745.0a	878.3bc	708.5de	1180.0	787.6bc	1746.3
Red Bobs	1988.3b	802.9c	958.3a	1225.7	727.9c	1970.1
Thatcher	1885.9b	800.2c	767.8cde	1167.5	696.78c	1957.7
Apex	1765.9b	854.8bc	808.5bcd	1080.0	826.3bc	1429.3
LSD (P=.05)	437.8	180.6	116.7	135.9	132.8	966.8
CV	14.6	13.4	9.56	7.93	10.6	36.6

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Red Fife provided very good weed suppression at Vonda in 2005, although weed biomass data was not significant between varieties (Table 31). However, this difference was significant when contrasted to the other varieties as a whole, Red Fife had 65.5 kg ha^{-1} less weed biomass than the others.

TABLE 31. Weed Biomass Data from Cereal Variety Trial in Vonda 2005.

Variety	Weed Biomass *kg ha^{-1}*
Thatcher	164.5
Apex	136.1
Superb	112.5
Red Bobs	101.56
Marquis	100.9
Barrie	100.2
Lee	79.9
Red Fife	48.1

Contrasts	Estimate	SE	DF	t statistic	P > |t|
Red fife vs. all others	-65.5	31.34	35	-2.09	0.0489

Oat variety had an overall significant effect on yield (Table 32). Morgan out yielded all other varieties with the exception of SA98084 and Calibre. Under conventional agriculture Morgan has one of the highest yield potentials of oat varieties. Victory, Harmon, Garry, and Assiniboia were among the lowest yielding varieties. On average low input varieties yielded 130.7 kg ha^{-1} more than the other varieties. The heritage varieties produced significantly less yield when compared to the others, producing 239 kg ha^{-1} less. The modern varieties also produced significantly less yield when compared to all other varieties. However, the modern varieties averaged 163.7 kg ha^{-1} more yield than the heritage varieties.

TABLE 32. Oat Yield Data from Cereal Variety Trial.

Variety	Yield *kg ha^{-1}*	
Morgan	1978.6	a
SA98084	1898.5	ab
Calibre	1862.5	abc
SA98511	1750.5	bcd
Dancer	1700.1	cde
Assiniboia	1624.7	de
Garry	1611.1	de
Harmon	1542.6	de
Victory	1536.8	de

Contrasts	Estimate	SE	DF	t Value	Pr > |t|
Modern vs. all others	-123.6	52.6	40	-2.35	0.0237
heritage vs. all others	-239.0	55.4	40	-4.31	0.0001
low input vs. all others	130.7	92.8	40	2.08	0.0439
modern vs. heritage	163.7	65.6	40	2.5	0.0168

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Within site years, variety had a significant effect on weed biomass at Vonda in 2003 (Table 33). Garry had significantly less weed biomass production than the rest of the varieties. The heritage varieties averaged 17.9 kg ha -1 less than the other varieties. Conversely, the low input varieties produced 14 kg ha-1 more weed biomass than the others. On average, the modern varieties also produced more weed biomass than the heritage varieties.

TABLE 33. Weed Biomass Data from Cereal Variety Trial in Vonda 2003.

Variety	Weed Biomass *kg ha^{-1}*
Calibre	61.1a
SA98511	60.3a
SA98084	59.4a
Dancer	50.5a
Morgan	49.4a
Assiniboia	48.7ab
Harmon	45.2abc
Victory	33.2bc
Garry	32.4c

Contrasts	Estimate	SE	t Value	Pr > |t|
heritage vs. all others	-17.9	3.91	-4.6	0.0001
low input vs. all others	14.0	4.43	3.17	0.0042
modern vs. heritage	9.8	9.78	2.12	0.0449

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Barley variety had a significant effect on yield (Table 34). Low input varieties, SB98340 and SB97590, averaged the overall highest yield at 2111.3 and 2103.5 kg ha^{-1}, respectively. The genotype SB997590 has been released commercially as CDC Cowboy. The modern varieties CDC Dolly, CDC Copeland, and Manley also had high yields under organic production.

TABLE 34. Barley Yield Data from Cereal Variety Trial.

Variety	Yield *kg ha^{-1}*	
SB98340	2111.3	a
SB97590	2103.5	a
Manley	2082.3	a
Dolly	2065.9	a
Copeland	2038.7	a
Hannchen	1987.4	ab
Betzes	1964.1	ab
Conquest	1925.5	ab
Huskey	1888.5	ab
McGwire	1796.0	ab
SH97088	1767.7	ab
Scout	1559.6	bc
OAC21	1345.1	cd
HB353	1018.0	d
Tupper	1015.9	d

Contrasts	Estimate	SE	DF	t Value	Pr > |t|
Low input vs. all others	189.4	125	70	1.49	0.1403

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

Weed biomass data was collected at three of the site years, Elbow 2003 and Vonda 2003 and 2005. Vonda 2005 had significant differences among weed biomass (Table 35). The low input line SB97590 had the greatest weed suppression with only 21.2 kg ha^{-1} of weed biomass.

In contrast, the modern variety, CDC McGwire was poor at weed suppression, producing 127.8 kg ha^{-1} of weed biomass.

TABLE 35. Weed Biomass Data from Cereal Variety Trial in Vonda 2005

Variety	Weed Biomass *kg ha^{-1}*	
McGwire	127.8	a
HB353	111.9	ab
Tupper	92.52	abc
Scout	72.53	abcd
SH97088	66.73	bcd
Hannchen	60.76	bcd
Conquest	58.54	bcd
Huskey	54.24	dc
Copeland	49.54	dc
Dolly	48.1	dc
Betzes	38.22	dc
SB98340	34.65	d
OAC21	32.43	d
Manley	27.2	d
SB97590	21.22	d

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

There were not any significant differences in the yield of durum wheat cultivars overall or at any site year (data not shown).

In summary the wheat varieties responded differently than the barely and oat varieties. In wheat, the heritage variety Red Fife had the highest yield potential under low soil nutrient organic conditions. This was possibly due to the longer growing season that it has. In contrast oat and barley heritage varieties tended to yield less than modern and low input varieties. Barley and oat genotypes selected for low input agriculture did quite well under organic conditions. This lends support to the idea that genotypes can be selected specifically for organic conditions. Because of the design of this experiment we cannot directly compare these results to conventional agriculture. Thus, we cannot say definitively that these varieties performed better under organic conditions *compared* to conventional conditions. Nevertheless we believe that the low soil nutrient conditions of actual organic farms provided the best test regime for these genotypes.

3.6 Experiment 6. Wheat Seeding Rate Study.

Objective

The objective of this experiment is to determine the optimal seeding rate for wheat under natural weed population in an organic production system.

Materials and Methods

This experiment was conducted in 2003 at Elbow and Vonda, in the brown and thin black soil zones, respectively. Trials were seeded as a four replicate RCBD. AC Elsa Wheat was seeded at densities of 250, 313, 375, 500 plants m^{-2} in 8 inch row spacing. The experiment was conducted on cereal stubble at all locations. All sites were tilled prior to seeding (Table 36).

Post emergent harrowing was used to control early flushes of weeds at all sites. Plant density, plant height, plant and weed biomass dry weight, plant head counts, and weed density data were collected throughout the growing season. Plant and weed density counts were recorded approximately one month after seeding, using 1/4m^2 quadrants (50cm x 50cm) at the front and back of each plot. Biomass samples were collected at 12 weeks, using 1/4m^2 quadrants at the front and back of each plot. Samples were dried in a drying oven at 70 °C for a 48 hour period. All samples were averaged to provide values for each plot.

TABLE 36. Soil Nutrient Analysis for Wheat Seeding Rate Study in 2003.

Soil Property	**Location**	
	Vonda	Elbow
Nitrogen (NO_3-N)	34.5	20.4
Phosphorus (P_2O_5-P)	6.2	5.4
Potassium (K)	339	120.8
Sulfur (SO_4-S)	7.4	5.3
pH levels	6.9	7.4

Results and Discussion

Seeding rate differences had no significant effect on any of the trial parameters (Table 37). This may be due to extensive grasshopper damage.

TABLE 37. Summary of Means for Data collected at Vonda and Elbow in 2003

	Vonda						Elbow				
Seeding Rate	Plant Density	Biomass Crop	Biomass Weed	Plant Ht	Head Counts	Grain Yield	Plant Density	Biomass Crop	Biomass Weed	Plant Height	Grain Yield
pl m^{-2}	*pl m^{-2}*	*g m^{-2}*	*g m^{-2}*	*cm*	*head m^{-2}*	*kg ha^{-1}*	*pl m^{-2}*	*g m^{-2}*	*g m^{-2}*	*cm*	*kg ha^{-1}*
250	178b	237a	58.1a	54a	225b	650a	183c	88.4a	101a	35a	-
313	194b	221a	65.7a	51a	223b	557a	261b	87.1a	70a	31a	-
375	228ab	230a	58.3a	50a	302ab	710a	258b	84.8a	90a	32a	-
500	269a	241a	43.6a	49a	340a	553a	376a	87.2a	73a	30a	-
LSD (P=.05)	44.5	51.3	17.6	4.7	71.6	207.1	49.1	27.7	34.1	4.7	
Standard Dev	27.8	32.1	11.0	3.0	44.7	129.5	30.7	17.3	21.3	3.0	
CV	12.8	13.8	19.5	5.8	16.4	21.0	11.4	20.0	25.5	9.3	

Values within a column followed by the same letter are not significantly different according to lsd (0.05).

3.7 Experiment 7. Optimum seeding rate for three annual green manure crops: the effect of weed competition.

Objective

To determine the optimum seeding rate for Trapper forage pea, AC Greenfix chickling vetch, and Indianhead black lentil as green manure crops under variable weed pressures.

Materials and Methods

In 2003, three experiments were established in the Saskatoon area, located in the dark brown soil zone. The land was managed organically for the year of the experiment but had been previously cropped to conventional wheat. The experiment was a three factor split plot design with weed treatment (weedy or weed-free) as the main plot. Combinations of the three species (pea, chickling vetch , and lentil) and five plant densities (10, 24, 64, 160, 400 pl/m^2) were fully randomized within the main plots as sub plots. Wild oat (*Avena fatua*) and wild mustard (*Brassica kaber*) were sown to supplement the natural weed community in the weedy treatment. Crop and weed population densities, and crop and weed biomass (at early bud and full bloom) data was collected throughout the growing season. Biomass samples from the early bud stage were also analysed for nitrogen content. Marginal cost analysis was examined to determine the profitability of each green manure species.

Results and Discussion

Figures 6, 7, and 8 show the accumulation of biomass as population density increases for each crop species under weed pressure. The points on these graphs represent observed yields at actual measured plant population densities from three sites. The curves were fitted using the indicated equations found in each graph. Biomass increased for each species between early bud and full bloom across all seeding rates.. Trapper field pea produced the most biomass, followed by AC Greenfix chickling vetch and Indianhead lentil.

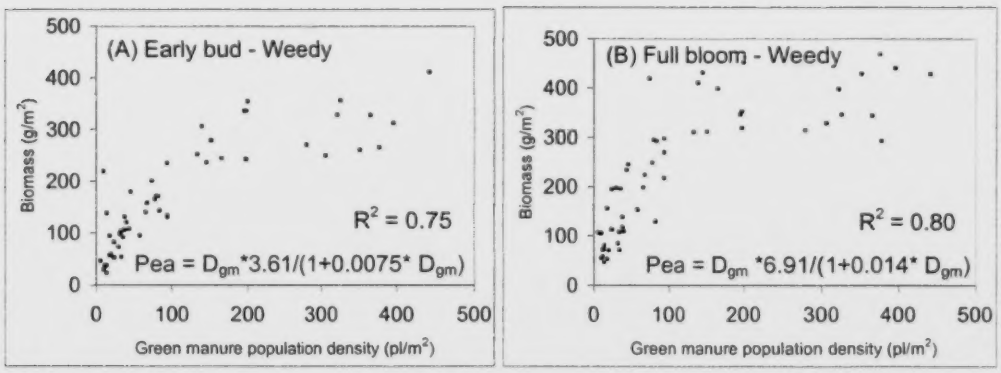

FIGURE 6. Effect of seeding rate on biomass accumulation in Trapper pea under weedy conditions at (A) early bud and (B) full bloom.

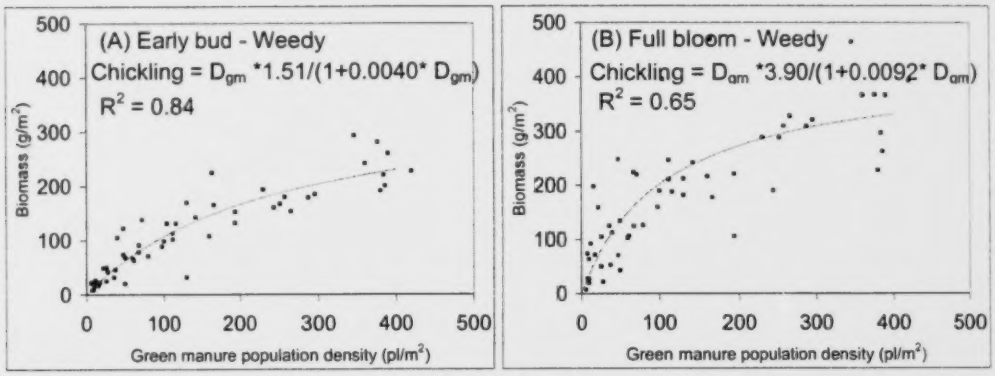
(A) Early bud - Weedy
Chickling = D_{gm} *1.51/(1+0.0040* D_{gm})
R^2 = 0.84
Biomass (g/m^2)
Green manure population density (pl/m^2)
(B) Full bloom - Weedy
Chickling = D_{gm} *3.90/(1+0.0092* D_{gm})
R^2 = 0.65
Biomass (g/m^2)
Green manure population density (pl/m^2)

FIGURE 7. Effect of seeding rate on biomass accumulation in AC Greenfix chickling vetch under weedy conditions at (A) early bud and (B) full bloom.

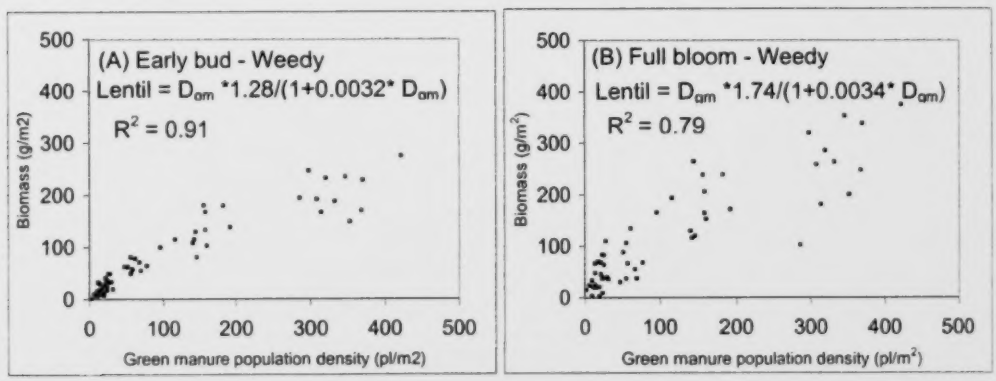
(A) Early bud - Weedy
Lentil = D_{gm} *1.28/(1+0.0032* D_{gm})
R^2 = 0.91
Biomass (g/m2)
Green manure population density (pl/m2)
(B) Full bloom - Weedy
Lentil = D_{gm} *1.74/(1+0.0034* D_{gm})
R^2 = 0.79
Biomass (g/m^2)
Green manure population density (pl/m^2)

FIGURE 8. Effect of seeding rate on biomass accumulation in Indianhead lentil under weedy conditions at (A) early bud and (B) full bloom.

The following graphs summarize the last three figures showing only the fitted curves and compare the weedy and weed-free treatments for all three species (Figure 9). Trapper pea produced the most biomass under weedy conditions. AC Greenfix chickling vetch and Indianhead lentil produced similar biomass when terminated at early bud. When left to compete with weeds until full bloom, AC Greenfix chickling vetch significantly out produces Indianhead lentil. However, under weed-free conditions, this differential yield between AC Greenfix chickling vetch and Indianhead lentil was not observed between early bud and full bloom.

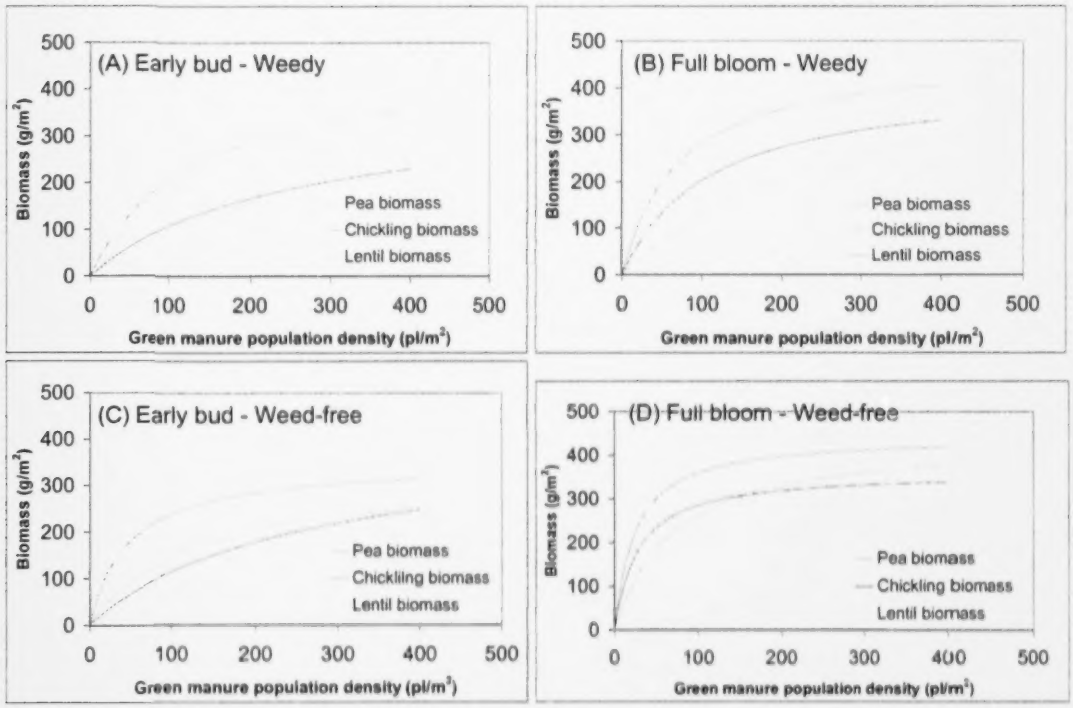

FIGURE 9. Effect of seeding rate on biomass accumulation in Trapper pea, AC Greenfix chickling vetch, and Indianhead lentil for (A) Early bud - Weedy (B) Full bloom – Weedy (C) Early bud - Weed-free (D) Full bloom - Weed-free

A comparison of the biomass yield curves between weed treatments revealed that only the weed-free treatments reach a point of constant final yield. Under weedy conditions, even at the high seeding rates, the green manure crops do not reached their asymptotes. Thus indicating that higher seeding rates are required under weedy conditions.

Not only does crop density have an effect on green manure biomass production, it also effects weed biomass production (Figures 10, 11, and 12). The points on the graphs represent observed yields at actual measured plant population densities. The curves were fitted using the indicated equations found in each graph. As expected, increasing green manure plant population density resulted in decreasing weed biomass. Also, weed biomass increased between early bud and full bloom stages. This increase in weed biomass between the two harvest dates was more significant than the increase in crop biomass. This trend is consistent amongst all three crops and suggests that under weedy conditions, early incorporation results in a greater proportion of nitrogen fixing biomass.

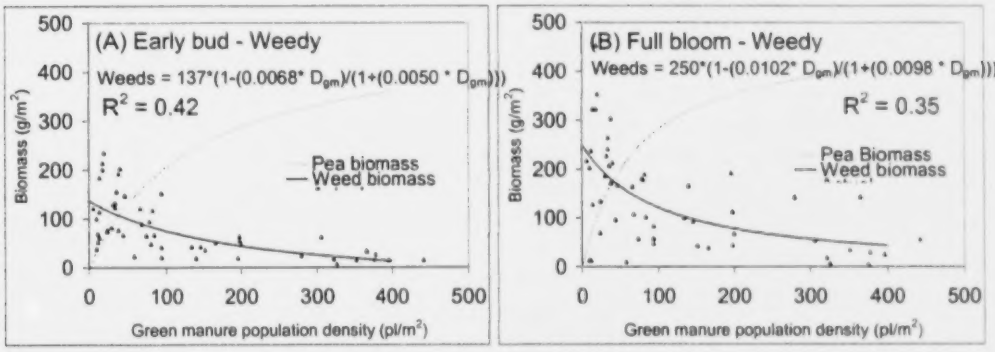

FIGURE 10. Effect of Trapper pea seeding rate on weed biomass accumulation at (A) early bud and (B) full bloom from all locations in 2003.

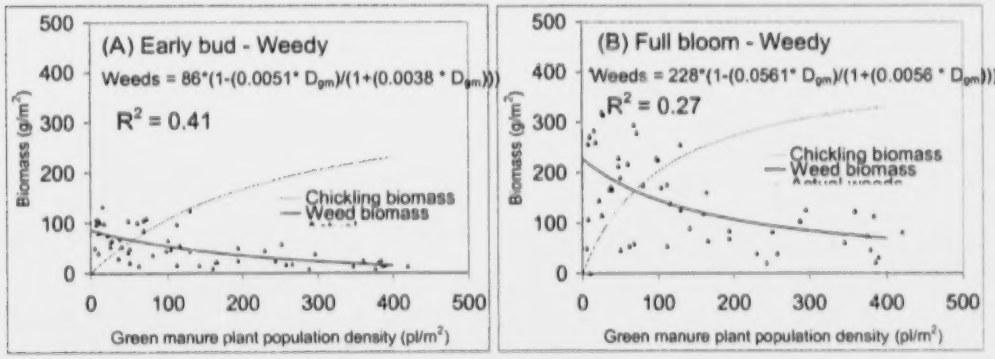

FIGURE 11. Effect of AC Greenfix chickling vetch seeding rate on weed biomass accumulation at (A) early bud and (B) full bloom.

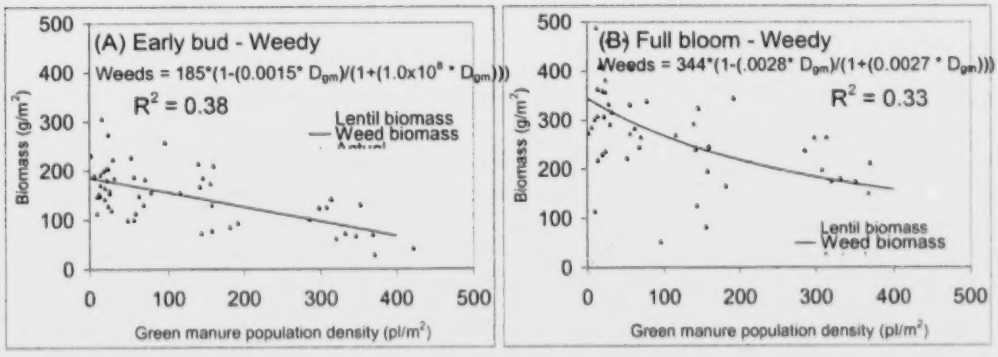

FIGURE 12. Effect of Indianhead lentil seeding rate on weed biomass under weedy conditions at (A) early bud and (B) full bloom.

Weed biomass was highest for Indianhead lentil and lowest for Trapper pea and AC Greenfix chickling vetch. Thus, AC Greenfix chickling vetch was able to suppress weeds with less biomass compared to Trapper pea. This may be an important observation for producers in

dry areas that are concerned about weed control and moisture conservation when choosing a green manure crop.

Biomass production as well as the concentration of nitrogen in the biomass determines the total nitrogen yield of a green manure crop. There are no significant differences in % biomass N between the three green manure species examined (figure 13) thus suggesting that biomass production was the main influence on total nitrogen production (Figure 14).

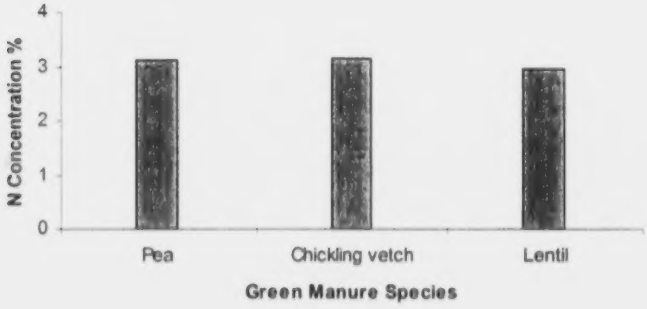

FIGURE 13. Nitrogen concentration of pea, chickling vetch, and lentil.

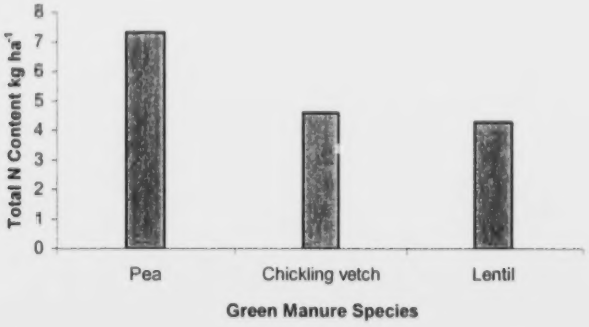

FIGURE 14. Total N content of pea, chickling vetch, and lentil.

To develop meaningful seeding rate recommendations, biomass productivity and nitrogen yield of a green manure crop were compared to relative seed costs. Marginal cost analysis was used to determine the plant population density at which the change in seed cost to grow one more green manure plant per unit area is equal to the change in value of the yield of a subsequent wheat crop per unit area. This model was based on previously discussed data as well as on necessary assumptions to complete the model (Table 38).

The marginal cost of increasing green manure plant populations density ha^{-1} and the marginal revenue of subsequent wheat yield increases ha^{-1} was calculated for each green manure species. The plant population density at which the marginal revenue of wheat per unit area equaled the marginal cost of green manure seed per unit area determined the economically optimum plant population density for each green manure crop.

TABLE 38. Summary of model assumptions for marginal cost analysis of optimum plant population densities for three green manure legumes.

Assumption	Value	Source
Nitrogen mineralized from annual green manure crops in the first year	20-40%	Ladd et al., 1983; Ladd and Amato, 1986; Janzen et al., 1990; Bremer and van Kessel, 1992
Wheat yield response to nitrogen fertilizer		McKenzie et al., 1997; Alberta Agriculture, 2001
Average soil nitrogen level for organic farms in Saskatchewan	19.17 kg ha^{-1}	Knight and Shirtliffe, 2003
Average price for organic No1 Red Spring wheat	\$0.32 kg^{-1}	Saskatchewan Research Council, 2003
Seed costs in 2003 for:		Wagon Wheel Seeds of Churchbridge, SK;
Trapper field pea	\$0.48 kg^{-1}	Gary Meier Core Farm of Ridgedale, SK;
Indianhead lentil	\$0.66 kg^{-1}	Johnson Seede of Arborg, MB;
AC Greenfix chickling vetch	\$0.70 kg^{-1}	personal communication, 2004

Marginal cost analysis determined the economically optimum plant population density for all three green manure crops based on their nitrogen contribution to a subsequent wheat crop. This analysis relied on two functions, marginal cost and marginal revenue (Figures 15 and 16). The marginal cost of green manure seed increased with increasing green manure plant population density due declining percent emergence. Marginal revenue of predicted yield increases for a subsequent wheat crop declined with increasing plant population density. Two marginal revenue functions were included in the analysis; the high marginal revenue curve assumed 40% mineralization of green manure nitrogen in the first year and the low marginal revenue curve assumed 20%. The rate of decline in marginal revenue differed between the low and high marginal revenue functions.

The point at which the marginal revenue functions intersected the marginal cost function indicated the most profitable plant population density based on the assumed rate of green manure nitrogen mineralization. Under weed-free conditions, the recommended plant population density for black lentil was 223 plants m^{-2} (high) and 184 plants m^{-2} (low). Optimal plant population densities for field pea were 60 plants m^{-2} (high) and 45 plants m^{-2} (low). No profitable plant population density was found for chickling vetch at the lower nitrogen mineralization level because of its very high seed size and cost. However, when assuming the higher rate of nitrogen mineralization, the recommended plant population density was 32 plants m^{-2} (Figure 15).

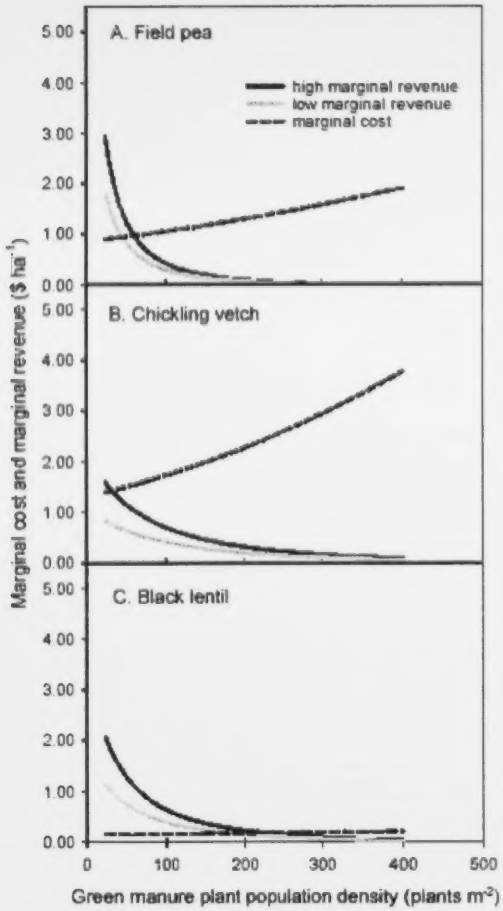

FIGURE 15. Marginal cost analysis of optimal plant population densities for (A) field pea, (B) chickling vetch, and (C) black lentil under weed-free conditions. High and low marginal revenue are based on the assumption of 40 and 20% nitrogen mineralization (respectively) of nitrogen found in incorporated green manure biomass.

Under weedy conditions, higher plant population densities were recommended. The rate for lentil was 300 plants m^{-2} (high) and 223 plants m^{-2} (low). Since lentil has a very small seed size, it is possible to establish high plant population densities at a low cost. Recommendations for field pea were 78 plants m^{-2} (high) and 49 plants m^{-2} (low). No profitable plant population density was found for chickling vetch at the lower nitrogen mineralization level under weedy conditions. At the higher rate of nitrogen mineralization, the recommended plant population density was 24 plants m^{-2} (Figure 16).

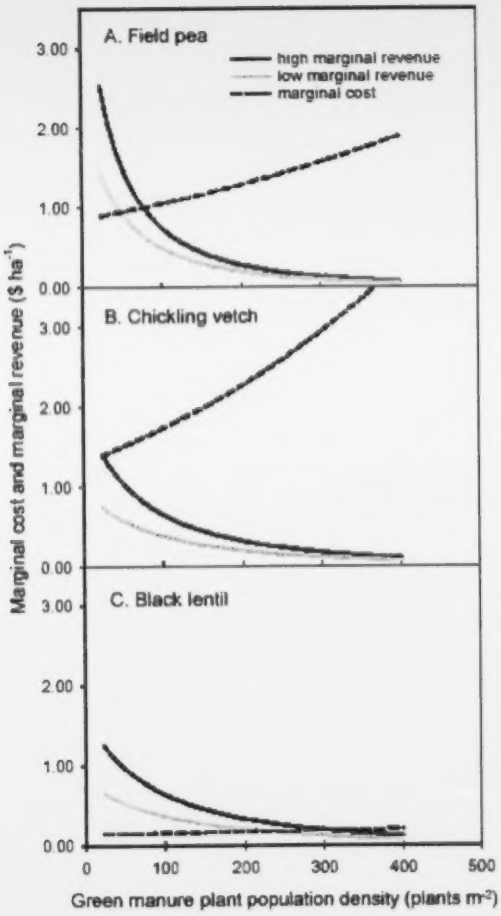

FIGURE 16. Marginal cost analysis of optimal plant population densities for (A) field pea, (B) chickling vetch, and (C) black lentil under weedy conditions. High and low marginal revenue are based on the assumption of 40 and 20% nitrogen mineralization (respectively) of nitrogen found in incorporated green manure biomass.

The density recommendations generated from marginal cost analysis for field pea are within the range or lower than the current plant population density recommendations for seed production of field pea (60 to 90 plants m^{-2}) (Park and Lopetinsky, Saskatchewan Pulse Growers, 2000; 1999; Wallace, 2001). However, the lentil recommendations are higher than the current seed production recommendations (80 to 130 plants m^{-2}) (Park and Lopetinsky, Saskatchewan Pulse Growers, 2000; 1999; Wallace, 2001). Although no current plant population density recommendations exist for chickling vetch, the low plant population density for chickling vetch of 50 to 55 plants m^{-2} used in some studies (Biederbeck et al., 1993; Bullied et al., 2002) seem appropriately low given the low profitability of chickling vetch.

3.8 Experiment 8. Green manure seeding rate study.

Objective:

To examine the optimum seeding rate for Trapper forage pea, AC Greenfix chickling vetch, and Indianhead black lentil as green manure crops under organic growing conditions, as recommended by the results of Experiment 7. In essence this experiment attempts to validate the results of the previous experiment on organic farms.

Materials and Methods:

This experiment was conducted in 2004 at Saskatoon (Kernen Research Farm) and Vonda, in the dark brown and thin black soil zones, respectively. Trials were seeded as a four replicate RCBD. Trapper field pea, AC Greenfix Chickling vetch, and Indianhead lentil were seeded in 8 inch row spacing, at densities of 40, 150, and 300 plants m-2 (pea and vetch), and 100, 200, and 400 plants m-2 (lentil). The experiment was conducted on cereal stubble at both locations. All sites were tilled prior to seeding. Plant density, plant and weed biomass dry weight, and weed density data were collected throughout the growing season. Plant and weed density counts were recorded approximately one month after seeding, using $1/4m^2$ quadrants (50cm x 50cm) at the front and back of each plot. Biomass samples were collected at early bud and late bloom stages, using $1/4m^2$ quadrants at the front and back of each plot. Samples were dried in a drying oven at 70 °C for a 48 hour period. All sub samples were averaged to provide values for each plot.

Results and Discussion:

This experiment had heavy weed pressure at the Kernen site, while the Vonda site had very little weed growth. Trends observed in the optimum rate trial (Exp 7) were similar to trends in these trials under both high and low weed pressure at the Kernen and Vonda locations respectively (Figure 17 and 18). Biomass production was similar for pea and chickling vetch under weed free conditions, however under weedy conditions, pea proved to be more competitive. Lentil grew well under low weed pressure, but under weedy conditions was most effective at higher seeding rates (300 pl m^{-2}). Chickling vetch grew well under relatively weed free conditions. However, due to the large seed size of this crop and seeding rates required under moderate to heavy weed pressure, this crop is not recommended as a green manure plowdown.

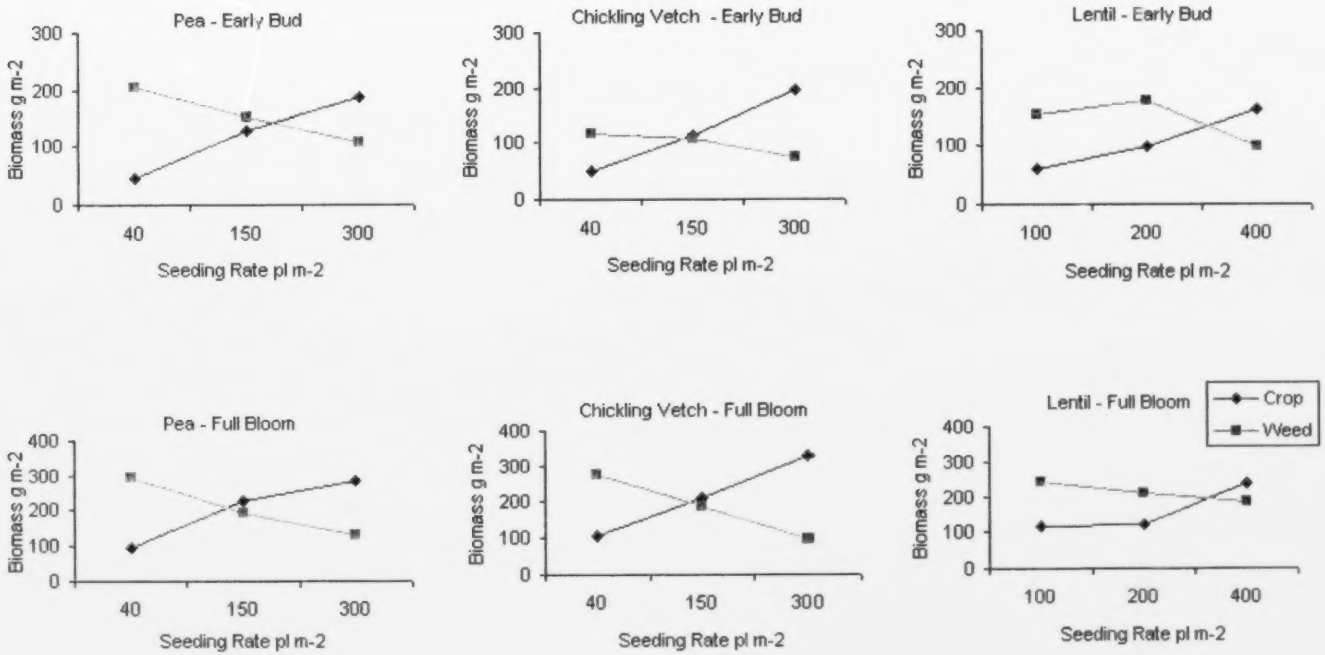

FIGURE 17 Biomass Production of Trapper pea, AC Greenfix Chickling vetch, and Indianhead lentil at early bud and full bloom stages at Kernen in 2004.

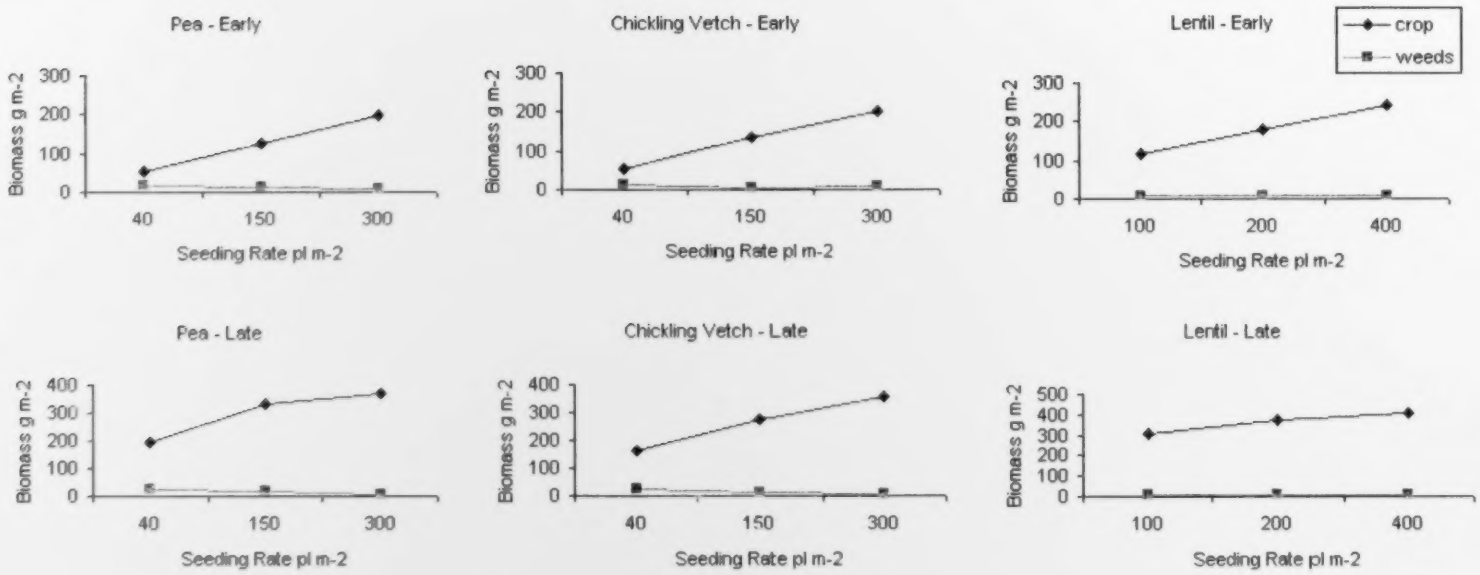

FIGURE 18. Biomass Production of Trapper pea, AC Greenfix Chickling vetch, and Indianhead lentil at early bud and full bloom stages at Vonda in 2004

4.0 Conclusions

Experiment 1.

We observed a small but significant overall increase in yield due to the application of rock phosphate in the year of application. It is unlikely that the addition of rock P will produce an economic return for organic producers, but it may provide a long-term measure for returning P to the soils. In the short-term, soils contain sufficient stores of P. But with continued harvest and export of P from the land, without returning it, soils will become more and more inherently deficient. Overall applications of *P. bilaiae* increased yield in the treatment crops. *Penicillium bilaiae* applied in combination with rock P was no more effective than *P. bilaiae* applied alone, indicating that it is not preferentially solubilizing P from rock P over soil P. While short-term plant available P supplies are increasing yields, eventually without the addition of some form of P the soils will become increasingly unable to meet the supply.

Experiment 2.

The application of composted manure was effective in increasing plant P uptake and tissue concentrations, as well as total biomass production and yield at all of the sites except the adequately fertile Kernen site. In general, annual applications were more effective than single applications, although there was carry-over of the single applications into subsequent years. Because manure has a higher ratio of P:N than plant tissues, there is risk of excessive build-up of P in the soil with over application of manures. However, because of the lack of inorganic fertilizer applications on organic farms, this risk would be very small in an organic system. In a situation where a lot of manure is available for field application, producers should apply it at rates based on the P content rather than the N content.

Experiment 3.

Early incorporation of green manure crops is essential in order to conserve soil moisture and have a positive influence on crop yield in the subsequent year. Of all the green manure crops examined, Indianhead lentil proved to be the most promising, with respect to biomass production and weed competition. Increased seeding rates of lentil for better weed control are recommended. In cool, wet years, oilseed radish is recommended as it grows very well under these conditions. Buckwheat is not recommended as a green manure crop in organic production, as it struggles under low nutrient conditions. Fenugreek and Nitro alfalfa should also be avoided under organic production as they are difficult to establish and compete poorly under moderate to heavy weed pressure. Chickling vetch grows moderately well under organic conditions, however due to high seeding rate requirements and large seed size, it is not recommended.

Experiment 4.

Based on the results of the two green manure experiments we can make some general recommendations regarding the use of green manures in organic systems. Regardless of the green manure crop utilized, early incorporation is recommended to

conserve soil water resources. There may be some exceptions in especially wet areas of the province. Generally speaking sweetclover was the best green manure for supplying N and P. Again use of this crop will be site dependent since it is a perennial crop and can cause soil drying. Producers in the brown soil zone tend to be reluctant to grow sweet clover because of its water demands. Of the annual green manures tested Indianhead lentil performed fairly well in terms of its N and P contribution to the subsequent crop. It also had moderate weed suppression at most of the sites. Oilseed radish and fall rye also performed well for supplying nutrients as well as controlling weeds, but because they are non-leguminous they not add N to the system. It was also difficult to source seed for the oilseed radish. Both of these crops may have a place in organic management systems, particularly for weed control. Most of the legumes (except nitro alfalfa) in addition to fixing N and thus adding N to the system, were quite effective at solubilizing P. It appears to be unnecessary to grow crops like buckwheat (which performed poorly) specifically for P solubilization, as the legumes are able to perform this function.

Experiment 5.

In the wheat varieties, Red Fife shows more suitability to growth under low nutrient conditions.

No significant differences in yield between the durum varieties were observed. There also seems to be no indication of varietal preference in durum when grow under organic conditions.

In the oat comparison, both AC Morgan and Calibre were the most successful varieties grown. SA98084 also proved to be a good yielder under organic conditions.

Several barley varieties yielded consistently, including SB98340, CDC Dolly, SB97590, CDC Copeland, and Manley. SB97590 is a modern low input variety which has recently been approved for registration, and will be registered as CDC Cowboy.

Experiment 6.

Further study is required to establish recommended wheat seeding rates under natural weed populations in organic cropping systems. The site at Elbow grew poorly due to drought and grasshopper pressure. Limited data was collected from the trial at this location. Results of this study at the Vonda location were inconclusive, due to grasshopper pressure.

Experiment 7.

Optimum plant densities under weed free conditions ranged from 184 to 223 plants m^{-2} for lentil, 45 to 60 plants m^{-2} for pea, and 0 to 32 plants m^{-2} for chickling vetch. Under weed pressure, densities ranged from 223 to 300 plants m-2 for lentil, 49 to 78 plants m-2 for field pea, and 0 to 24 plants m-2 for chickling vetch..

Low seed cost, high nitrogen fixation, rapid growth rate, high water use efficiency, and good weed competition are desirable characteristics for annual green manure crops. Lentil had the lowest seed cost and seed size of all three green manure species in this study. It was also shown to have the least weed biomass suppression ability. As a result, high plant densities are recommended for lentil under moderate to heavy weed pressure. Field pea had the greatest ability to compete with weeds among all

three crops. At very high densities, few differences in crop biomass production were observed between low and high weed pressure. Due to high biomass production, pea also accumulated the highest levels of total nitrogen. And although it had higher seed costs than lentil, field pea is best suited as a green manure crop under organic conditions. Chickling vetch was the least economically feasible crop of the three species, due to a limited nitrogen contribution, a very large seed size, and high seed cost. It is not recommended as a green manure crop under organic conditions.

Experiment 8.

Conclusions for this experiment are similar to the previous. Due to the high weed competition, high biomass production, and high nitrogen accumulation of pea, it is best suited as a green manure crop under organic conditions. Lentils are a suitable option, when seeded at high plant densities, especially under heavy weed pressure. Chickling vetch proved to be a moderate green manure crop. However due to the large seed size and high seeding rates, it is not economically feasible under organic production.

3.4 Information of Benefit to Producers, Processors or Government

All of the above information is of direct benefit to producers.

4 Personnel

A personnel report will be supplied.

5 Equipment

No equipment was purchased.

6 Project Developed Materials

No project materials are yet available.

7 Project Photos

Please see Appendix 1.

8 Acknowledgements

Soils and Crops, 2003, Lawley, Soils and Crops 2005 by Shirtliffe Scott 2002-2005 organic field day (Shirtliffe, Knight and Brandt) various other extension talks by Shirtliffe, Brandt and Knight.

9 Expense Statement

An expense statement has been supplied by the U of S business office.

10 ICAR Registration

This project is registered with ICAR.

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Appendix I.

TABLE 1. Summarized weather data for 2002 – 2005 for the Vonda, Elbow, Scott and Kernen organic trial locations. Monthly mean temperatures and total monthly precipitation are presented.

Year	Location	May	June	July	August	September
			Average temperature (°C)			
2002	*Vonda*	8.3	17.1	20.0	16.4	11.1
	Elbow	7.9	16.0	19.7	15.6	11.4
	Scott	8.0	16.4	19.3	15.6	10.2
2003	*Vonda*	11.7	16.2	18.7	20.4	10.8
	Elbow	11.1	15.6	20.2	21.5	11.4
	Scott	10.4	14.4	17.8	20.0	10.3
2004	*Vonda*	8.4	13.6	17.4	14.2	10.7
	Elbow	13.6	14.2	17.8	15.3	12.2
	Scott	7.9	12.6	16.6	14.0	9.9
	Kernen	7.9	13.0	17.0	13.9	13.2
2005	*Vonda*	10.8	15.3	18.9	16.4	12.6
	Elbow	8.4	14.4	18.4	16.2	12.0
	Kernen	9.8	14.6	18.0	15.3	11.4
			Total precipitation (mm)			
2002	*Vonda*	0.0	62.2	71.6	85.0	57.0
	Elbow	16.9	81.2	34.8	106.4	44.6
	Scott	2.5	68.6	31.8	41.8	48.8
2003	*Vonda*	16.6	33.6	53.9	31.8	32.4
	Elbow	39.2	25.0	86.0	27.0	34.0
	Scott	21.8	34.2	66.0	44.6	43.8
2004	*Vonda*	31.0	90.0	64.8	73.0	20.2
	Elbow	15.8	62.4	68.6	68.0	30.0
	Scott	36.5	52.0	69.4	44.4	15.4
	Kernen	36.0	86.7	75.3	73.0	20.2
2005	*Vonda*	29.4	171.0	44.4	54.0	81.6
	Elbow	53.8	176.8	37.8	46.2	72.8
	Kernen	27.6	173.2	57.0	84.0	92.4

Table 2. Chemical Analysis of Idaho Rock Phosphate (Soda Springs Phosphate Inc., Soda Springs, Idaho)

Element		Concentration (%)
Sulfur	S	0.75
Phosphorous	P Total	11.66
	P Available	2.79
Potassium	K	0.22
Magnesium	Mg	0.34
Calcium	Ca	27.92
Sodium	Na	0.61
Iron	Fe	0.64
Aluminum	Al	0.40
Manganese	Mn	0.02
Copper	Cu	0.01
Zinc	Zn	0.13

Figure 1.1. Buckwheat late incorporation green manure at Kernen in 2004.

Figure 1.2. Chickling vetch late incorporation green manure at Kernen in 2004.

Figure 1.3. Fenugreek late incorporation green manure at Kernen in 2004.

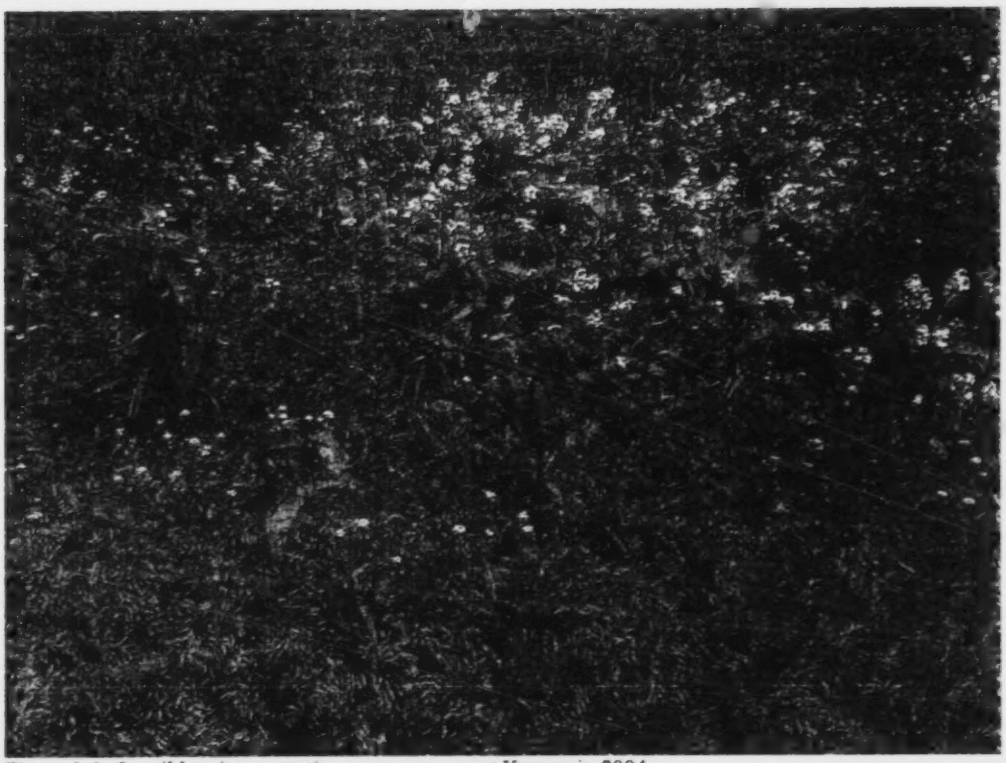

Figure 1.4. Lentil late incorporation green manure at Kernen in 2004.

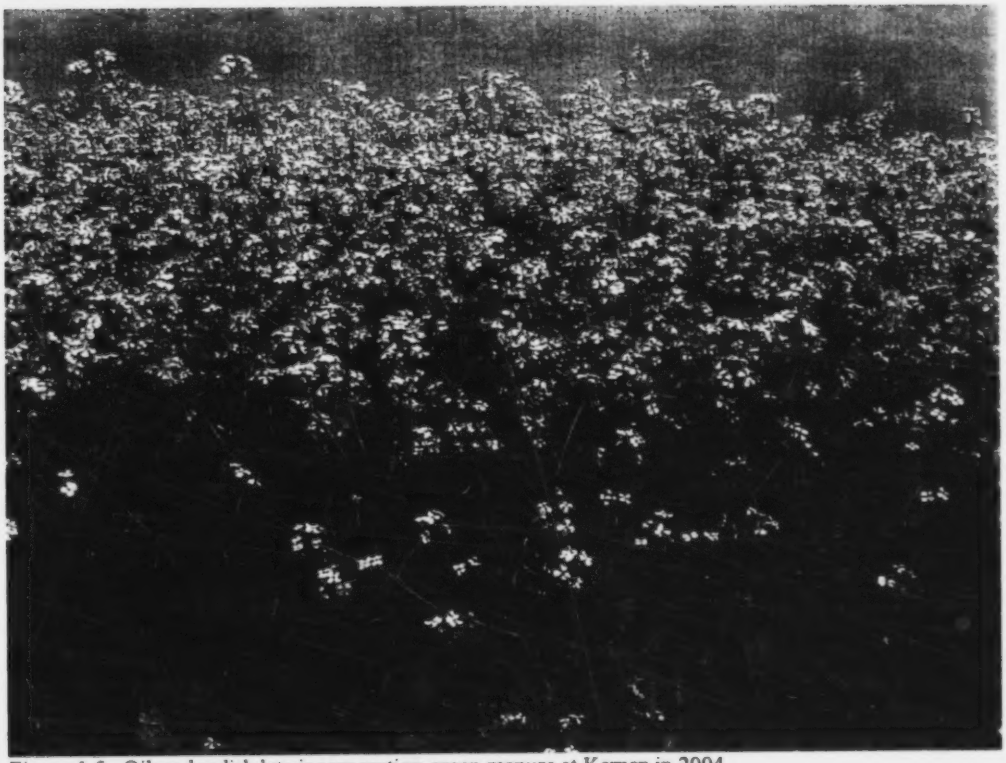

Figure 1.5. Oilseed radish late incorporation green manure at Kernen in 2004.

Figure 1.6. Annual green manure trial at Kernen in 2004.

Figure 2.1. Oilseed radish green manure at Vonda in 2004.

Figure 2.2. Buckwheat green manure at Vonda in 2004.

Figure 2.3. Rye green manure at Vonda in 2004.

Figure 2.4. Rye and sweet clover plots at Vonda in 2004.

Figure 2.5. Chickling vetch green manure at Elbow in 2004.

Figure 2.6. Rye green manure at Elbow in 2004.

Figure 2.7. Green manure plots (sweet clover and chickling vetch) at Elbow in 2004.

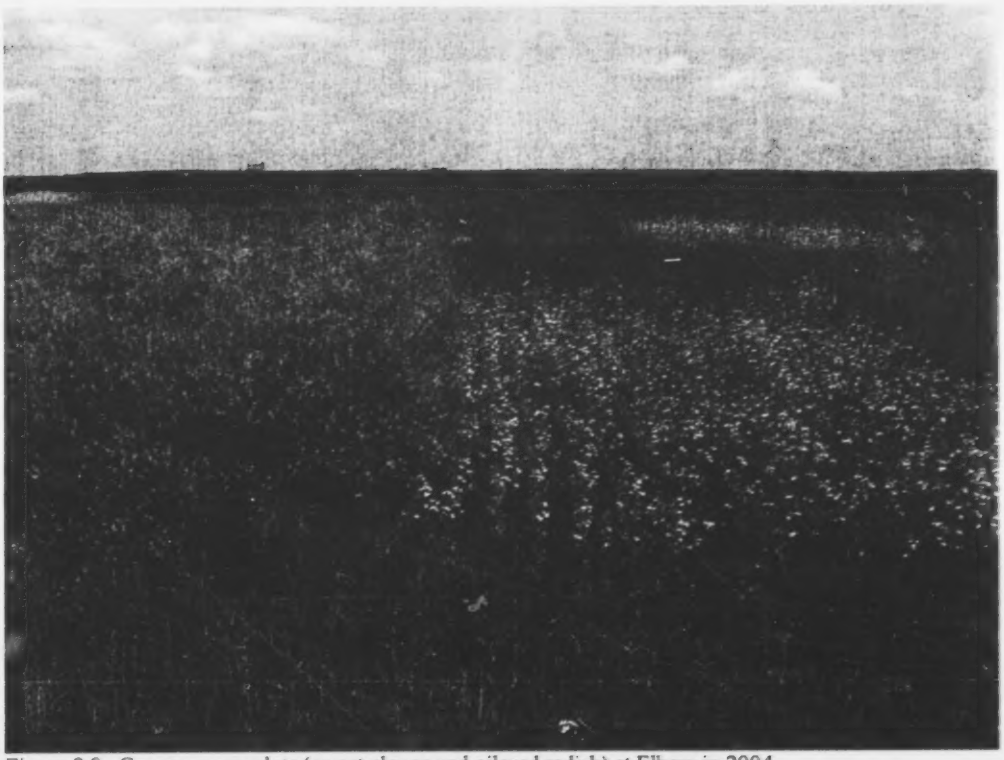

Figure 2.8. Green manure plots (sweet clover and oilseed radish) at Elbow in 2004.

Figure 2.9. Discing late incorporation green manure plots at Elbow in 2004.

Figure 3.1. Barley variety trial at Vonda in 2004.

Figure 3.2. Post harrowed barley plot in variety trial at Vonda in 2004.

Figure 3.3. Wheat variety trial at Vonda in 2004.

Figure 3.4. Post harrowed wheat plot in variety trial at Vonda in 2004.